

WEST VIRGINIA
GEOLOGICAL SURVEY



WEST VIRGINIA
GEOLOGICAL SURVEY.

VOLUME THREE.

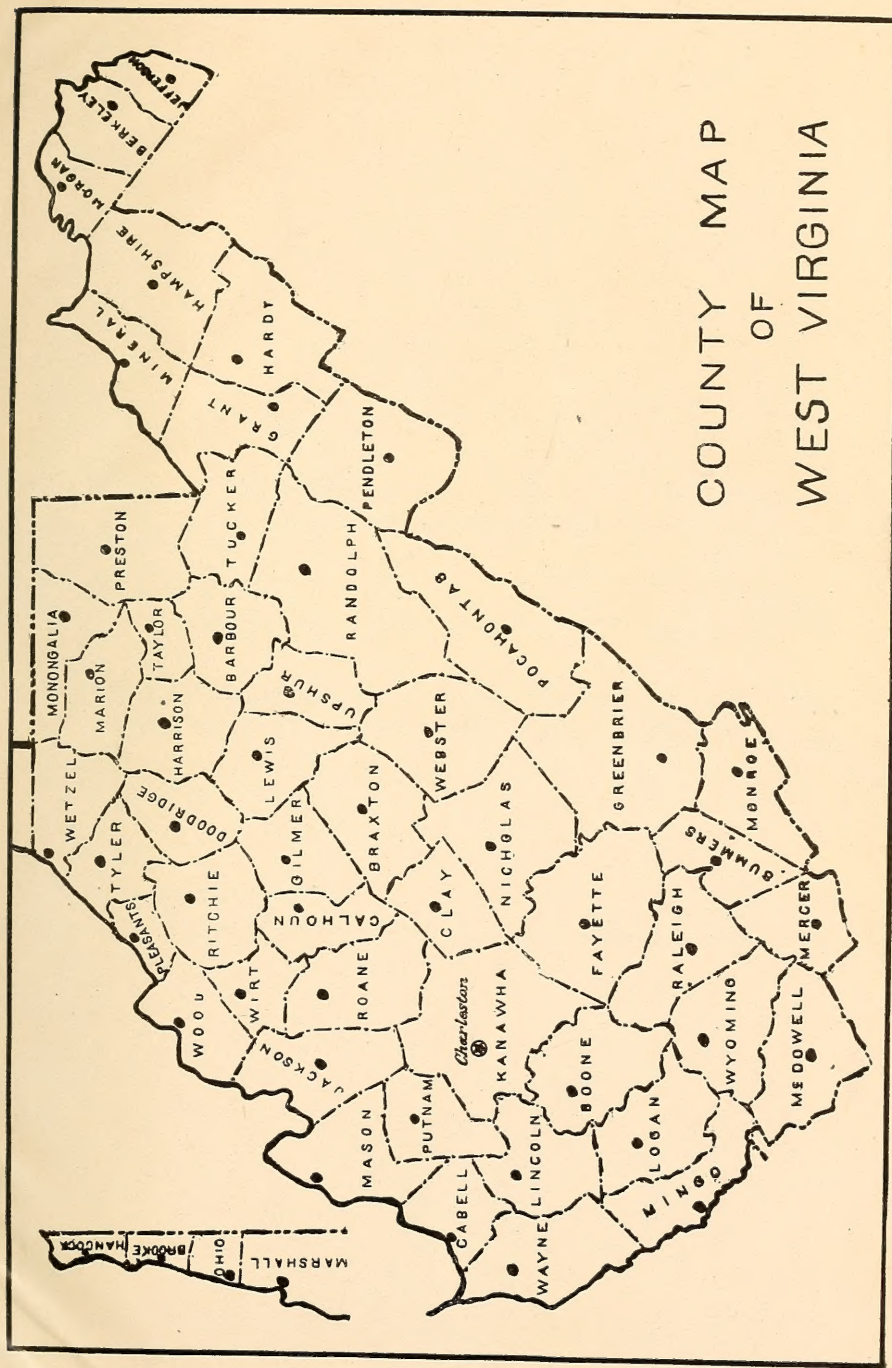


Clays, Limestones, and Cements.

BY

G. P. GRIMSLEY, Assistant State Geologist.

I. C. WHITE, State Geologist.



COUNTY MAP OF WEST VIRGINIA

Plate I.—Outline County Map of West Virginia.

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LETTER OF TRANSMITTAL.

To His Excellency, Hon. Wm. M. O. Dawson, Governor of
West Virginia and President of the State Geological Survey
Commission:

SIR—

I have the honor and pleasure of transmitting herewith Volume III. of the State Geological Survey Publications, on Clays, Limestones, and Cements. To the preparation of this valuable work, Professor George P. Grimsley, its author, has devoted practically all of his time and energy since he became connected with the Survey, in September, 1904. While West Virginia is very rich in Clays and Limestones, their development, except in limited areas, has, up to the present time, been practically neglected by the industrial world, largely because nothing of a scientific or official nature had been published concerning them. No state in the Union possesses such unlimited resources for the manufacture of Portland Cement, all forms of lime, and sand-lime brick, as well as of everything in which the several kinds of clay form a conspicuous part, so that the publication of this report, wherein the great natural wealth of the state in these raw materials is so clearly and skillfully set forth, may well mark the beginning of a new epoch in West Virginia's manufacturing growth.

Professor Grimsley started the cement industry in the state of Kansas, where it has attained great success, and already, through his investigations and efforts, two large enterprises of this kind have just been undertaken in West Virginia, at either of which \$400,000 to \$500,000 of capital will be invested in most productive establishments. These will prove only the beginning of the developments that the publication of this volume is sure to bring, in the way of

utilizing the state's raw materials, and thus adding to the population and prosperity of the commonwealth.

The subject of Ores and Building Stones will now be taken up by Professor Grimsley, and will form the subject matter of Volume IV. of the Survey series. It will be published at the earliest date possible. The field work on the sample volume of detailed county geology has already been largely completed by Professor Grimsley and the other members of the Survey staff, and will be published before the close of the present year, as well as a supplementary Report on Coal, to be known as Volume II.-A, that will be prepared by myself. In this Coal Report the southwestern portion of the state, which could not be adequately treated in Volume II., will receive special consideration.

The edition of Volume III. will be 2,500 copies, all bound in cloth, and the price has been fixed at \$1.50 when purchased separately, or at \$1.00 only when ordered in combination with the other volumes and maps of the Survey. The plan of selling the publications at practically the cost of printing has proven very satisfactory, since it places them in the hands of those who will make the best use of them, and thus enables the Survey to supply a constant demand for information concerning the State's natural resources.

Very respectfully,

I. C. WHITE,
State Geologist.

Morgantown, April 1st, 1906.

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PREFACE.

The present volume of the West Virginia Geological Survey treats of a group of resources not before described, and which represent most valuable assets of a state rich in the possession of mineral wealth. The clay, lime and cement resources of this state are rich in possibilities, but comparatively poor in development. At the present time these industries are all attracting marked attention in this country, and an active search is being made for good deposits of these products located near lines of transportation. It is, therefore, an opportune time for the issuance of such a report for this district.

West Virginia is a state of 24,780 square miles, traversed by 4,000 miles of railroads and 300 miles of navigable waters, in addition to the 256 miles of the Ohio river. From its borders it is only 90 miles by rail to Pittsburg, 56 to Washington, 81 to Baltimore, 175 to Philadelphia, 273 to New York, and 396 to Norfolk.

A careful reading of the following pages will show that the West Virginia deposits of clay, lime and cement materials are of high quality, large extent, well located, merely needing capital to change them into commercial products which will enrich the operators as well as the state. It is the hope of the writer that this volume, sent to the various portions of this state and the country, will result in an active development of these industries.

In part I. attention is called to the section on prospecting for clays, with suggestions for simple tests, and observations which do not require an expert to apply. It is hoped that owners of such materials will read this section before sending samples to the Survey office for an opinion on their value. A small piece of clay or other rock with no other data as to extent, etc., is useless for examination.

Stoneware is shipped in car load lots from other states into every city of this state, while at the same time it possesses

large and valuable deposits of clay suitable for the manufacture of all classes of stoneware, with fuel unrivaled for cheapness near at hand. In spite of all these advantages there are only two stoneware factories in the entire state. In paving brick this state was the pioneer, but has since fallen to low rank in total production through the neglect of development of its valuable paving brick clays. Charleston has the honor of the inauguration of this great industry, and to-day no paving brick is made at that place, though the clays are adapted to the manufacture of a high-grade product. The fire brick industry of West Virginia amounted in 1904 to less than \$12,000, and the following pages will show where very pure refractory clays of good thickness are undeveloped, and during the past year the daily press has commented on the scarcity of fire brick on the market. Ornamental and fancy trimming brick are made on a small scale at Charleston, otherwise the industry is undeveloped, while very few cities are without buildings in which such brick are used and shipped from other sections.

The sand lime brick industry is growing very rapidly in this country, and while not made in this state, its importance justifies a chapter in this volume. A study of clay statistics shows that the value of clay products in West Virginia in 1904 was over two million dollars, of which nearly one-half is represented by the output of the white-ware potteries.

The lime industry is mostly confined to the eastern Panhandle counties, where rock of exceptional purity (99 per cent.) is found, as well as almost theoretically pure dolomites. The state holds fifth rank in limestone for furnace flux, and eighteenth in the production of lime. The total output of lime industry in 1904 amounted to \$644,363.

A study of the part devoted to lime will show large limestone and lime resources with comparatively small development, and this condition exists when it is impossible to buy lime in quantity on less than 30 to 60 days' notice. It will be a matter of interest and possibly surprise to many people of the state to read of the variety of uses of limestone and lime. One use of lime which deserves especial attention from the farmers of this state is its value on soils, not as a fertilizer, but as a corrective medium for acid non-productive soils.

The Portland cement industry of the United States ten years ago amounted to less than a million barrels, while to-day over twenty-six million barrels are made and used in this country. There are eighty-three cement mills in seventeen states, with Pennsylvania the leading producer. In West Virginia there is a single mill. The part of this report on cement describes the process of manufacture, machinery required, cost of manufacture, and cost of construction and equipment of a mill. The chapter on possible cement locations in the state should give some idea of the wonderful possibilities of a future cement industry in West Virginia, and the chapter on uses shows the cause of the great development of the industry, since cement is now replacing many former materials of construction. It was considered profitable to gather together in one chapter these manifold uses.

The work of a State Survey is, in part, the collection and publication of material which will describe the existing mineral development of a state, and of greater value to distribute data which represent possibilities of undeveloped mineral resources, thus arousing interest which will result in such development. This volume is issued with these objects in view, and returns have come in even before the book was set in type. Brief accounts of these possibilities have been printed in advance of this volume through the newspaper and technical press, and inquiries have been made by men of capital with regard to these locations. At the present time three companies are considering the erection of large cement mills in West Virginia, and have purchased the land. This work is the result of the investigations of the Survey in connection with this volume.

In the present volume an effort has been made to include all available facts from reliable sources bearing on the subject of clay, lime and cement, that were regarded as helpful in a correct understanding of the value of the deposits in this state. Works of other surveys and technical treatises have been freely consulted in the larger libraries of the country, and data have been taken from these works. Credit for such information is given in the foot-note references. Under the subject of clay the work of Professor Edward Orton, Jr., has been especially helpful. In the discussion of the geology of the state, the reports of Dr. I. C. White, State Geologist, have been constantly

used, and the facts from his studies incorporated into this volume have added to the value of the work. The writer wishes in this connection to express his appreciation of this valuable work of Dr. White, which has been practically donated to this state for the advancement of its mineral development. The writer is also under obligation to Dr. White for advice and suggestions in connection with this report.

The assistant chemist of the Survey, F. F. Grout, has done most creditable work on the subject of plasticity of clays, on the mechanical tests, and analyses of clays, limestones, and limes. His work on physical tests of clays, brick and lime should be of direct value to the manufacturers, and shows that these products made in West Virginia are of high quality. His work has been accurate and painstaking, and he has been especially faithful in the discharge of all his duties, proving of great assistance to the writer in the completion of this volume.

Acknowledgements of favors granted to the Survey are due to the various companies of the state, especially those who have kindly furnished us with samples for study and have expressed their interest in many other ways. To the Scioto Lime and Stone Co., of Delaware, O., and Ash Grove Lime Co., of Ash Grove, Mo., for samples of stone and lime for use in our lime tests. To R. L. Humphrey for the description and plates illustrating the Buckhorn Portland Cement Co. mill, and for the illustrations in the chapter on testing of cement. To E. L. Soper, of Hunt Eng'r. Co., of Iola, Kansas, for the tests on different length rotary kilns. Also to the various machinery companies for the loan of figures and plates used in illustrating this volume as listed below, for the description of these machines, and to the railroad companies whose lines penetrate the various parts of this state, for favors granted.

This volume is issued to the public with the hope that it may be of some value in the promotion of the mineral development of a state already known as a mineral state.

G. P. GRIMSLEY.

MORGANTOWN, W. VA., March 24, 1906.

ILLUSTRATIONS FOR USE IN THIS VOLUME LOANED BY:

American Road Machinery Co., Kennett Square, Pa.
Stevenson Brick Machinery Co., Wellsville, Ohio.
Henry Martin Brick Machine Manufacturing Co., Lancaster, Pa.
American Clay Working Machinery Co., Bucyrus, Ohio.
C. & A. Potts & Co. (Brick Machinery), Indianapolis, Ind.
C. W. Raymond Brick Machinery Co., Dayton, Ohio.
Stedman's Foundry and Machine Co., Aurora, Ind.
Williams Patent Crusher and Pulverizer Co., St. Louis, Mo.
Standard Dry Kiln Co., Indianapolis, Ind.
Chisholm, Boyd & White Brick Press Co., Chicago, Ill.
Patterson Foundry and Machine Co., East Liverpool, Ohio.
Ohio Valley Clay Shingle Co., Huntington, W. Va.
Schwarz System Sand-Lime Brick Co., New York City.
H. Morris, Machinist (Columbia Press), Philadelphia, Pa.
American Sand-Lime Brick Co., Chicago, Ill.
Morgan Construction Co. (Gas Producer), New York City.
S. W. Shoop & Co. (Lime Kilns), Altoona, Pa.
Clyde Iron Works (Lime Hydrating Machinery), Duluth, Minn.
American Lime Hydrating Co., Baltimore, Md.
Broomell, Schmidt & Steacy Co. (Lime Kilns), York, Pa.
Kent Mill Co., New York City.
Allis-Chalmers Co. (Cement Machinery), Milwaukee, Wis.
F. L. Smidth & Co. (Cement Machinery), New York City.
The Bonnot Co. (Cement Machinery), Canton, Ohio.
Ruggles-Coles Eng'r. Co. (Dryers), New York City.
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Richard L. Humphrey, Cement Engineer, Philadelphia, Pa.
Dr. A. C. Lane, Michigan Geological Survey, Lansing, Mich.
Winget Concrete Block Machine Co., Columbus, Ohio.
Normandin Cement Machinery Co., Jackson, Mich.
D. N. Harper, Publisher of "Concrete," Detroit, Mich.
Jackson Cement Sewer Pipe Co., Jackson, Mich.
Dodge Manufacturing Co. (Cement Machinery), Mishawaka, Ind.
"The World's Work," New York City.
"The Cement Age," New York City.

PART I.
Preliminary Report on the Clays
of
West Virginia.

CHAPTER I.
THE ORIGIN OF CLAYS.

CHAPTER II.
THE CHEMICAL PROPERTIES OF CLAYS.

CHAPTER III.
THE PHYSICAL PROPERTIES OF CLAYS.

CHAPTER IV.
CLASSIFICATION AND USES OF CLAYS.

CHAPTER V.
TECHNOLOGY OF THE CLAY INDUSTRIES—BRICK AND TILE.

CHAPTER VI.
TECHNOLOGY OF THE CLAY INDUSTRIES.
POTTERY AND SEWER PIPE.

CHAPTER VII.
RESUME OF THE TOPOGRAPHY AND GEOLOGY OF WEST VIRGINIA.

CHAPTER VIII.
DESCRIPTION OF THE WEST VIRGINIA CLAY INDUSTRY AND THE
GEOLOGICAL HORIZONS OF THE BEDS.

CHAPTER IX.
THE RIVER CLAY INDUSTRIES OF WEST VIRGINIA.

CHAPTER X.
PHYSICAL TESTS ON WEST VIRGINIA BUILDING AND PAVING
BRICK.

CHAPTER XI.
SAND—LIME BRICK.

CHAPTER XII.
A STUDY OF STATISTICS.

CHAPTER I.

THE ORIGIN OF CLAY.

INTRODUCTION.

It would be difficult to find a more common substance, or a more useful one than clay. Its distribution is universal, its uses manifold, its varieties almost unlimited, its age beyond human computation. From the time man, regarded as an example of refined clay, first stepped forth in the garden, its great value has been recognized by the human race.

From clay to clay, his worldly cycle is supposed to run, so in the world about us the cycle is likewise from clay to clay. On every hillside the waste of the rock and wear of the landscape form are visible. The tearing down process is ever apparent, and the removal of the detritus from higher to lower levels is a matter of every day observation. In the course of time, centuries and even aeons, the highlands will form the lowlands, and from the mountain upland will be fashioned the level lowland. Earth's forces may again, as in past eras, uplift the lowlands to the high plateaus into which streams will cut their channels, frost and rain and the varied forces of air will carve their characteristic sculpture; so the work goes on unceasingly from the beginning to the end of time. The scenery of today will not be the scenery of the geological tomorrow, nor will it correspond to that of the geological yesterday. Change is the order of time.

The clay of the mine and the soil of the field are results of change. They are not original products of the earth, but have been formed by decay.

DEFINITION AND ORIGIN OF CLAY.

Clay may be defined as an earthy substance composed of a base of kaolin, mingled with a greater or less percentage of mineral and organic impurities; therefore, possessing a variable chem-

ical composition, and having certain physical properties, all of which determine its value or utility to mankind.

In the beginning of its history, clay doubtless came from certain silicate minerals, especially feldspar, components of the so-called hard or crystalline rocks. The feldspar family is one of many members and complex composition, made up essentially of the chemical elements, potassium, sodium, lime, aluminum, silicon and oxygen.

The potash feldspar (orthoclase) and those high in soda (albite) through alteration form the mineral kaolin or kaolinite which is the basis of clay; while the lime feldspars (anorthite, etc.) change into another group of minerals less useful, but more beautiful in form and color, known as the zeolites.

The true potash feldspar known to mineralogists under the name of orthoclase, has a chemical formula $K_2O, Al_2O_3, 6 Si O_2$, and is described as a potassium aluminum silicate. This hard, brilliant mineral has a look of stability, and apparently to the unaided eye would change as slowly as the clear quartz pebble. When examined in thin sections with the microscope, these clear crystals are seen to be already clouded by a multitude of dark specks of alteration products proved by tests to be bits of kaolin. It is the exception, rather than the rule, to find unaltered orthoclase in the rocks of the earth.

This new mineral, kaolin, which is not an original one, but secondary in its origin, has the chemical composition of $2 H_2O, Al_2O_3, 2 Si O_2$, often with part of the water replaced by potash. This formula, compared with the orthoclase formula above, shows a substitution wholly or in part of water (H_2O) for the potash (K_2O). This change, known to chemists as *hydration*, results in an increase of bulk which causes the feldspar eventually to become fissured and broken and thus to crumble.

A loss of four parts silica ($Si O_2$) is also seen by comparing the two formulae, and this further weakens the apparently strong orthoclase mineral. Thus is broken down one of the components of such hard rocks as the everlasting granites and syenites. These rocks must therefore fall apart to form the soil and debris of atmospheric waste, for the rock like the chain of steel can be no stronger than its weakest link, which, in this illustration, is orthoclase feldspar.

In this alteration of orthoclase to kaolin, there is a loss in volume of 54.44 per cent., or if changed to kaolin and quartz the loss is 12.57 per cent. While the kaolin is formed especially from orthoclase and other acid feldspars, it has also been noted as an alteration product of the following aluminous minerals: Andalusite, anorthoclase, biotite, cyanite, epidote, leucite, microcline, nephelite, plagioclase feldspar, scapolites, sillimanite, sodalite, topaz, zoisite.¹

WEATHERING AND THE FORMATION OF CLAY AND SOIL.

These various alterations in the rock texture and composition are included under the term *weathering*, or the alteration of rocks under atmospheric and aqueous agencies.

The great agent of change in the rocks in the surface portion of the earth is water with its included gases and acids. What is termed pure water in the earth's surface or crust, as it is often called, is pure only by comparison. Even the water as it falls from the clouds and before it reaches the earth is impure, containing gases and dust. These included gases are powerful agents of change and their power is augmented by increase in amount on contact with the earth.

The water now reaching the earth becomes an active geological and chemical agent, both by direct wear on the rocks termed *corrasion*, and by its chemical action or *corrosion*. The gases and acids especially important in water as a chemical agent of change are carbonic acid (CO_2), oxygen (O), sulphur (S or in form of SO_3), humus or vegetable acids.

Carbonic Acid.—Rain water contains a certain percentage of carbonic acid gas, and as it passes into the earth receives additions especially from decaying vegetable matter. In 10,000 parts of air of average purity there are three parts of this gas, and in rain water the amount is about 30 times greater.

All living forms are exhaling this gas and it is found in the air, in the sea, and in the rocks of the earth in the form of carbonates of the mineral bases. In ordinary limestone, carbonic acid (CO_2) forms one-fifth of the weight of the rock.

1. U. S. Geological Survey Monograph 47, p. 352.

Water, containing carbonic acid and reinforced by humus acids, attacks the rocks with great strength. Limestones are dissolved, the potash or soda is removed from the feldspars and from other silicate minerals and water substituted, the changes resulting in rock disintegration and decay.

Oxygen.—Rain water also contains oxygen, which is an important constituent of the air, and which is essential for life. This element is ever present and possessing a strong affinity for nearly all the other elements, becomes an important agent of alteration.

The circulating water, as it meets substances lacking their full quota of oxygen, gives up a part of its supply to these substances, a process termed *oxidation*. The ferrous iron (FeO) may thus receive a half more oxygen and form the sesquioxide or ferric iron (Fe_2O_3), called hematite, coloring the substance red; or, it may take water in addition, forming the limonite group of iron compounds ($\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$), giving yellow and brown colors. The latter change is apt to be the more usual one under ordinary conditions. Iron being present in nearly all rocks in greater or less amount, these changes become very common and are readily observed.

One of the very common iron compounds is the sulphide in form of pyrites (FeS_2) often bright yellow in color, and so confused by many with gold, whence its name of "fool's gold." In the presence of oxygen in water this mineral oxidizes, forming two new compounds, FeO and SO_2 . Further oxidation and hydration may change these to the ferric iron, hematite, or limonite, and the sulphur compound (SO_3) to sulphuric acid (H_2SO_4) which may then act on other mineral compounds forming sulphates.

In the presence of organic matter the oxygen may be removed from the mineral compounds. This *reducing* action changes sulphates to sulphides, renders insoluble iron coloring compounds, soluble, so that they are removed by the circulating waters and the substances thereby bleached. Downward flowing waters will thus sometimes leave an upper white clay or sand resting on a lower colored stratum. Red clays will be banded and streaked with white clays. Vegetable material in the clay will be surrounded by a halo of white.

It is thus seen that the oxygen reactions are complex and manifold, leading from one compound to another, producing marked changes in composition, accompanied by changes in color.

The clays formed by alteration of rocks are subjected to these various changes and their varied colors are to be explained in large part by these chemical reactions.

Humus Acids.—Under ordinary conditions, the surface of the earth is covered with a blanket of vegetable matter, living and decaying, known as *humus*. Among the products of this decay are carbonic dioxide, and certain organic compounds which in the presence of water form vegetable acids known as humus acids. Their exact composition and reactions are not known, but they have the power of dissolving mineral substances and so become important geological agents actively at work in the alteration of rocks.

These humus acids combine with iron, forming soluble compounds which are removed in the circulating waters thus effecting a leaching action, changing iron stained clays to white. They also have the unique power of changing certain silicates, and in their presence the insoluble silica becomes soluble.

When these acids are added to water already rendered a powerful chemical reagent through its carbonic gas content, they greatly increase its power for alteration and hasten rock decay, with its resultant products of soil and clay.

Sulphur.—The sulphur in circulating water, produced by decomposition of sulphides or sulphates, may be oxidized and uniting with water forms sulphuric acid (H_2SO_4), which then enables the water to attack the lime, magnesia, potash, soda and alumina in rocks forming sulphates. By this alteration the rock type is broken down.

It is through the agency of water with these reinforcements that rocks begin to crumble. The mechanical forces of frost, heat, cold, rain impact, running water aid in the work of rock alteration toward the common end of decay.

The original rocks of the earth's crust were in all probability igneous. Through their decay and disintegration were formed the sediments, later consolidated into the sedimentary rocks. In a later time these sedimentary rocks would be disintegrated, forming sediments for newer rocks.

In the first decay of the igneous rocks, clay would be formed, which *in situ* would be of high degree of purity and primary in its formation. A considerable portion would become mingled with the sediments and bound up in the sedimentary rocks, whose later

decay would form clay more impure than the primary clay and would be classed as secondary in origin. These secondary clays by transportation and mixture with foreign materials would become more and more impure.

WHAT IS CLAY?

Clay, from a chemical point of view, then, is kaolin, plus a greater or less amount of impurities. A chemically pure clay, if such existed, would be a pure kaolin formed from feldspar or other silicate decay as has been outlined. Absolute purity in rocks, as elsewhere, is a high ideal rather than a fact. The purer clays approximate the theoretical composition of the kaolin, while the more impure clays have a low percentage of the kaolin.

Kaolin.—The mineral kaolin has a chemical composition represented by the formula $2\text{H}_2\text{O}$, Al_2O_3 , 2SiO_2 , with a specific gravity of 2.6, and a hardness of 2 to 2.5. The mineral occurs massive rather than in crystals. It shows cleavage and the plates so formed are flexible and inelastic, rhomboidal or hexagonal in shape. Kaolin is smooth or soapy to the touch, has a strong affinity for water and when pure is white in color, but it is found in a great variety of colors. Theoretically, it contains:

Silica (SiO_2)	.....	4.65	per cent.
Alumina (Al_2O_3)	.....	39.5	" "
Water (H_2O})	.....	14.0	" "
		100.0	" "

According to Dana, the name kaolin is a corruption of the Chinese word, *Kauling*, meaning "high ridge," the name of a hill near Jauchau Fu, where the material is obtained.

The purest deposits of kaolin would be found near the place where the original mineral, feldspar or other silicate, had decomposed, but even here it would be impure through the admixture of other chemical elements of the original mineral and other minerals present in the rock. If the feldspar forming the kaolin was a constituent of a granite rock, mica flakes and quartz grains would be mingled with the kaolin. For these reasons, the chemical analyses of so-called pure kaolin do not agree with the theoretical composition given above.

The granite rock, selected as an example, is a complex chemical combination of elements, some of which form kaolin, and others form the impurities, visible as quartz grains and mica flakes, or invisible detected by chemical analysis.

The change of the granite to residual soil is shown in the following instructive series of determinations of Merrill¹. Column I. shows the chemical analysis of the granite in the District of Columbia; column II. the residual sand from the weathered granite; column III. the calculated percentage of loss of the various constituents of the rock; column IV. the calculated percentage of constituents saved:

Constituents.	I. Rock.	II. Soil.	III. Loss.	IV. Saved.
Loss on ignition.....	1.22	4.70	0.00	100.00
Silica (SiO_2).....	69.33	65.69	14.80	85.11
Alumina (Al_2O_3)	14.33	15.23	3.23	96.77
Ferric iron (Fe_2O_3) .....	.....	4.39	0.00	100.00
Ferrous iron (FeO)	3.60	.....	0.00	.....
Lime (CaO)	3.21	2.63	25.21	74.79
Magnesia (MgO)	2.44	2.64	1.49	98.51
Soda (Na_2O)	2.70	2.12	28.62	71.38
Potash (K_2O)	2.67	2.00	31.98	68.02
Titanium (TiO_2)	not det.	0.31	.....	.....
Phosphorus (P_2O_5)	0.10	0.06	40.00	60.00
	99.60	99.77		

This table is interesting in showing the alterations of the rock through weathering and the effect on the various chemical components. It also affords a clue to the origin of certain components of the clays. Thus, analyses of the West Virginia clays show all these elements present, even titanium and phosphorus are never absent. A type of high grade kaolin may be illustrated by the clay at Woodbridge, New Jersey, which gives the following analysis:²

Silica (SiO_2).....	42.23	per cent.
Alumina (Al_2O_3).....	39.53	" "
Water (H_2O).....	13.59	" "
Titanium (TiO_2).....	1.40	" "
Sand	0.50	" "
Potash (K_2O).....	0.41	" "
Soda (Na_2O).....	0.08	" "
Lime (CaO).....	0.10	" "
Iron (Fe_2O_3).....	0.50	" "
Water (free) (H_2O).....	1.21	" "

1. Rocks, Rock Weathering and Soils, pp. 207, 209.

2. Geological Survey of New Jersey, p. 297; 1878.

When this analysis is compared with the theoretical one, it is seen to be low in silica and combined water, also to contain a number of other compounds.

As the kaolin clays are farther and farther removed from their original place of formation, they become more and more impure and vary from the pure type. The clays remaining in the place where they were formed are spoken of as *residual clays*, while those removed to other places are called *transported clays*.

When clay is subjected to pressure, it is forced together and consolidated, and if the consolidation extends far enough, the clay becomes laminated in structure, and is then called a *shale*. If the shale be further consolidated and altered by great pressure and heat, as in mountain making movements, the shale is changed or metamorphosed into *slate*.

RESIDUAL CLAYS.

The type of residual clays would be represented by the kaolins described above, also by the various clays formed through the disintegration of rocks in place, so that they are found in the place of the parent rock resting on unaltered masses of the same.

The latter clays are usually oxidized, showing brown or red colors, due to the alteration of the iron compounds. Their composition depends not only on the character of the original rock, but also on the chemical changes which have taken place, and the character and amount of foreign material added by transporting agencies. They will not only differ in composition in various parts of the surface exposures, but also with depth due to the chemical changes, as illustrated by the following analyses, quoted by Merrill¹. Analysis No. 1 is of a limestone soil in Wisconsin three feet from the surface, and No. 2 of the same soil, four and one-half feet deeper, resting on the unchanged rock.

	I.	II.
	Per cent.	Per cent.
Silica	53.09	49.13
Alumina	21.43	20.08
Ferrie oxide.....	8.53	11.04
Ferrous oxide.....	0.86	0.93
Lime	0.95	1.22
Magnesia	1.43	1.92

1. Rocks, Rock Weathering and Soils, p. 306.

Soda	1.45	1.33
Potash	0.83	1.60
Water	10.79	11.72
Titanium	0.16	0.13
Phosphorus	0.03	0.04
Manganese	0.03	0.06
Carbonic acid.....	0.29	0.39
Carbon	0.22	1.09
	100.09	100.68

A study of these analyses shows the loss of soluble elements from the surface clay, as is seen in the iron, lime, magnesia, and potash. The higher percentage of silica in the surface portion shows a higher state of decomposition.

TRANSPORTED CLAYS.

In addition to the residual clays, there are large and valuable deposits of transported clays, no longer found in their original home. These have been carried to new locations by the various forces of nature; water, ice, and wind.

Alluvial Clays.—Water is the great agent of transportation. Rain washes the soil and clay down the slopes of hills, and rivers and creeks take up the load of sediment to carry it to more distant points. Streams are rarely free from sediment, they may carry a slight amount and be clear, or they may transport a heavy load, becoming muddy like the Missouri and Mississippi. When the current is slackened the load begins to fall, forming a deposit in the channel, on the flood plain, or in the basins into which they flow. Thus are formed the delta deposits of the Mississippi and other rivers, the lake deposits, or the flood plain terraces, all included under the term *alluvial*.

The Mississippi carries annually into the Gulf of Mexico seven and one-half billion cubic feet, or 490,000,000 tons of silt and mud, but a large part of its load of sediment never reaches this point, as it is spread out over the flood plains during high water. The work of this large river is repeated in smaller rivers, creeks and runs.

The alluvial clays along the Ohio river and its tributaries in this state and in the other drainage basins are used in the manufacture of brick at many places, as discussed in detail in Chapter IX.

Glacial Clays.—In a recent geological period, the northern part of this country was covered by glacial ice, which, passing over the rocks, ground them to sand, gravel and clay, which were left over this area. The glacial clays are often tough and compact, with oxidized surface passing down into the blue boulder clay, and varying in composition from place to place depending on the source of the materials. These clays are used in the manufacture of brick and drain tile in a number of states, but they are usually mixed with pebbles, boulders, and are often too high in lime.

Loess Clays.—With the melting of this great ice sheet, a flood of silt laden water spread out over level tracts below the end of the glacier, and passing down through the rivers caused them to spread out over the flood plains, there depositing a large part of the load of sediment forming the high water terraces.

In the Mississippi valley the fine silt was deposited over a wide area and of considerable depth. The fine silt soil, or clay, formed in this way in this valley has been called *loess* from the resemblance of its structure to that of the *loess* of China, which has a different mode of origin.

In the Ohio river valley the ice sheet had an important influence on the drainage features and the waters filled the valley and its tributaries, there spreading out and leaving a deposit of fine clay seen in the valleys of the Kanawha, Guayandot, Monongahela, and other rivers of southern, northern, and western parts of the state.

Aeolian or wind formed soils are found in a number of sections of the country, but aeolian clays do not form an important economic division.

This brief review of the conditions of origin of clays shows a very complicated history. The chemical and physical properties of clays to be described in subsequent chapters show variations which depend in part on the primary origin of the clay, but more on the various changes it has undergone before it reached the present location. In many of these West Virginia clays, the main points of their history can be determined, but the variations and ramifications of that history are unknown.

CHAPTER II.

THE CHEMICAL PROPERTIES OF CLAYS.

As has been described in the preceding chapter, clay is a complex mixture of parts. With its base of kaolin, it may contain the other minerals of the rock whose decay gave it existence. It will also contain various compounds brought in by the forces of air and water. If the clay has been transported from its place of origin, it will contain a variety of impurities gathered along the way.

These various foreign impurities not only alter the chemical composition of the clay, but exert an important influence on the behavior of the clay when it is molded, dried and burned into useful products. It will be the purpose of this chapter to indicate some of these impurities and to give a brief discussion of their effects.

Among the mineral impurities, the most common are feldspar, mica, quartz, and iron ores. In addition, there may be present in some clays a variety of other minerals, like chlorite, rutile, hornblende, calcite, gypsum, etc., but these occur usually in such small quantity that they may be for the most part neglected, as they are interesting rather than important.

Feldspar.—In the disintegration of the original rock, the feldspar is changed into kaolin, but some of the mineral may remain but slightly altered. The feldspar found in clays seldom retains the bright surface seen in the original rock, but has become cloudy through partial alteration. The crystals are usually broken and more or less rounded in outline, appearing in the form of small grains.

When present in any quantity, the feldspar grains have a similar effect to sand, decreasing the shrinkage at ordinary temperatures; but if the temperature of burning reaches the melting point of the feldspar (1200° C.), the mineral fuses and becomes an ac-

tive flux, so that its presence is injurious to clays intended for refractory purposes.

Mica.—This mineral is more common than feldspar in the clays of this state. It occurs in the form of bright sparkling flakes which are easily seen when the clay is examined in a bright light. Mica occurs in two forms, white or muscovite, a silicate of potash and alumina; black or biotite, a silicate of magnesia, alumina, and iron oxide.

The chemical composition of feldspar and mica are shown by the following analyses, from Clarke¹:

	Orthoclase. Per cent.	Muscovite. Per cent.	Biotite. Per cent.
Silica	65.09	45.40	34.67
Alumina	18.95	33.66	30.09
Ferric iron.....	0.36	2.36	2.42
Ferrous iron.....			16.14
Magnesium	0.00	1.86	1.98
Lime	0.42	....	....
Sodium	2.29	1.41	1.67
Potassium	12.95	8.33	7.55
Water .....	....	5.46	4.64
Titanium .....	....	1.10	....
Fluorine .....	....	0.69	0.28
Manganese .....	....	....	0.85
	100.06	100.27	100.29

In the burning of clays, the iron mica, biotite, may influence the color of the ware on account of its iron content. Mica aids in the fusion of the clay, but fuses at a slightly higher temperature than the feldspar. According to the experiments of Ries, mica lowers the plasticity and the tensile strength of clays.

Quartz.—This mineral is a common constituent of clays in the form of sand, and it has an important influence on the shrinkage which will be discussed in the section on shrinkage. Iron ores will be treated in the section on iron.

The chemical compounds found in clay are shown in the following analysis of a West Virginia clay (New Cumberland):

	Per cent.
Silica (SiO_2).....	59.76
Alumina (Al_2O_3).....	22.79
Ferric iron (Fe_2O_3).....	0.60
Ferric iron (FeO).....	3.53
Lime (CaO).....	0.59
Magnesia (MgO).....	1.23
Sodium (Na_2O).....	0.42

1. U. S. Geological Survey, Bull., 220, p. 25-71-75.

Potassium (K_2O).....	3.79
Water (H_2O).....	0.54
Phosphorus (P_2O_5).....	0.46
Titanium (TiO_2).....	0.82
Loss (Carbonic acid, free water, organic matter).....	5.26
Total.....	99.79

Silica.—Silica occurs in clay in two forms as free silica (quartz or sand), and combined silica found in the kaolin and other silicate minerals present (feldspar, mica, etc.). The combined silica in the pure kaolin would reach 46.5 per cent. This percentage in most cases would be decreased by the foreign impurities in clays.

An ordinary chemical analysis usually gives total silica including both the free and combined. Some analyses give the percentage of free and combined silica, separated by the latter being dissolved in potassium hydroxide and hot sulphuric acid. This method would include the combined silica of the kaolin and mica, but not of the feldspar, which is insoluble. The free silica represented by such an analysis would include the quartz and also the silica of feldspar which is in reality combined silica. The range of total silica in clays is shown in the following table, taken from Ries' report.¹

Quality.	Minimum.	Maximum.	Average.
Brick clays.....	34.35	90.877	59.27
Pottery clays.....	45.06	86.98	45.83
Fire clays.....	34.40	96.79	54.304
Kaolins	32.44	81.18	55.44

Up to the present time sixty-five West Virginia clays and shales have been analyzed in the survey laboratory and a study of these analyses gives the following range of silica:

	Minimum.	Maximum.	Average
Brick clays.....	46.89	78.12	62.99
Pottery clays.....	49.81	73.33	57.49
Fire clays.....	43.40	66.69	53.41

Free silica has an important effect on the shrinkage of clays as shown later. It may also affect the fusibility. Quartz alone is almost infusible, but in the presence of fluxing impurities it may fuse.

1. Bulletin New York State Museum, No. 35, p. 525; 1900.

Alumina.—Alumina is present in all clays and is one of the essential components. It forms an important part of the original minerals from which the kaolin base of clays is derived. In pure kaolin there would be 39.5 per cent of alumina. The fusion point of alumina is high but when the alumina is mingled with fluxing impurities in the clay this point is lowered, but always produces high shrinkage unless silica is present in sufficient quantity to counteract it. According to Seger¹, a large percentage of alumina has an effect similar to lime in destroying the red color of the iron.

In the West Virginia clays tested, except the river clays, the average percentage of alumina was 23.97, the minimum 19.32, and the maximum 39.55. In the river clays, which are usually of shallow depth and more or less sandy, the average percentage of alumina was only 15.12, the minimum 11.55, and the maximum 18.74.

Alumina is sometimes found in clays as alum or the hydrous sulphate of alumina and potash formed often through decomposition of pyrites of iron in the clay. Alum may be brought to the surface in drying or burning, forming a coating on the surface of ware, or at high temperatures in the kiln it may be decomposed, forming sulphuric anhydride gas, so causing blistering of the ware in its escape. Alum is readily soluble in water and if a source of trouble in clays, can be removed by washing.

Iron.—Iron is found in greater or less amount in all clays and determines the color in most clays. The iron may be present in the form of oxide in such minerals as magnetite, hematite, limonite, or as the sulphide in the mineral pyrite. The amount of iron oxide present in different clays is given by Ries² as:

	Minimum.	Maximum.	Average.
Brick clays.....	0.126	32.12	5.311
Fire clays.....	.01	7.24	1.506
Kaolins	trace	6.87	1.29

In the West Virginia clays examined to date, the following range of iron oxide occurs:

	Minimum.	Maximum.	Average.
Brick clays.....	0.94	10.73	6.02
Fire clays.....	0.95	7.20	3.86

1. Quoted by Ries, Bull., New York Museum, No. 35, p. 568.

2. Bulletin, New York State Museum, No. 35, p. 520.

The color of the burned clay, determined by the iron content, as outlined by this same author¹, is due: to the amount of iron oxide present, nature of the oxide, temperature of burning, condition of the kiln atmosphere. A small amount of iron present will leave the brick nearly white, and a larger amount will give the red color, deeper and deeper in shade as the amount increases. The ferric oxide (Fe_2O_3) gives a red color, ferrous oxide (Fe O) alone gives a green color, and the mixture of the two produces yellow, cherry, red, blue, and black.²

Burning these iron clays at a low temperature will give the pale salmon colored brick and the higher temperatures bring out the deeper red shades. In such clays the color is an index to the temperature used and therefore to the quality of the brick.

Since oxidation affects the color as described above, then the condition of the kiln atmosphere must have an important influence on the color of the burned ware. With an excess of oxygen in the kiln, the oxygen will change the ferrous oxide to the ferric and the fire is said to be *oxidizing*. If a low amount of oxygen be present in the kiln the ferric iron may lose part of its oxygen and so be reduced to ferrous iron with a corresponding change of color, and the fire is said to be *reducing*.

With good draft the flame in the kiln has a bluish color and is oxidizing; and with a poor draft giving a smoky kiln, the flame becomes yellow and is reducing. Iron in the ferrous state is more readily fused than in the ferric condition, so that a marked percentage of such iron is injurious in fire clays.

If the iron is present in the form of sulphide or pyrites, it may often be detected in the clay in small gold-like particles or even in larger concretionary masses. The larger masses are usually thrown aside in the process of mining clay. Iron pyrites is one of the most widely distributed minerals found in rocks, occurring in rocks of all geological ages and in nearly all localities. State surveys are continually receiving specimens of this mineral which is so often mistaken by people for gold or other valuable ore. It was long ago named *fool's gold*. Its chemical composition is iron sulphide, represented by the formula FeS_2 . This sul-

1. New Jersey Geol. Survey, vol. VI., p. 57; 1904.

2. Quoted from Ries, New Jersey Geol. Survey, vol. VI., p. 58.

phide readily weathers to the soluble sulphate, FeSO_4 , which is removed in circulating water.

When clay containing iron sulphide is heated, the mineral changes to the simple sulphide FeS , and at a higher temperature oxidizes, forming two compounds, ferrous iron FeO , and a gas SO_3 , which may escape from the kiln or may be further oxidized and in the presence of steam form sulphuric acid, H_2SO_4 . This acid is capable of dissolving many of the impurities of the clay, especially lime and magnesia. These dissolved minerals may pass to the surface and by evaporation leave a film or wash producing discoloration of the ware. Where a coal high in sulphur is used as fuel, the same result may be produced.

Lime.—Lime in clays is usually found in the form of carbonate CaCO_3 . In this form it may be detected by adding a few drops of hydrochloric or muriatic acid (HCl), which will act on the lime producing effervescence due to the escape of the carbonic acid gas (CO_2).

In some clays the carbonate is present in concretions varying from small pebbles to large boulders. These may be removed by hand separation. If the lime be distributed through the clay in fine particles, it will not injure the clay seriously for ordinary uses. If present in large masses, it will be converted in burning into quick lime (CaO) and the slacking of the lumps will fracture the ware.

At higher temperatures, the lime will unite with the other elements of the clay, especially the alumina and silica, giving a reaction which has a marked effect on the color and fusibility of the clay. If the lime be in excess of the iron, it has a tendency to give the burned ware a buff color. This effect is most marked according to Ries¹, when the percentage of lime is three times that of the iron. Such calcareous clays give the buff brick known as the Milwaukee shade, in Wisconsin and Michigan, where lime clays of glacial origin are used.

According to this same author, lime in sufficient quantity will cause the clay to soften rapidly, bringing the points of incipient fusion and viscosity within 76°F . (41.6°C .) of each other and thereby makes it difficult to vitrify such clays without softening the ware and destroying its shape and therefore its utility.

1. New Jersey Geol. Survey, vol. VI., p. 61.

Clays high in lime might still be used for ware burned at low temperatures, but would not be valuable for vitrified products. The range of lime in clays is given by Ries¹, as follows;

	Minimum.	Maximum.	Average.
Brick clays.....	0.024	15.38	1.513
Pottery clays.....	0.011	9.90	1.098
Fire clays.....	0.03	15.27	0.655

In the sixty or more clays examined in this preliminary survey the following range of lime was found:

	Minimum.	Maximum.	Average.
Brick clays.....	trace	10.94	1.35
Pottery clays.....	0.36	4.19	1.34
Fire clays.....	0.22	4.92	1.06

Lime Sulphate.—Lime is sometimes present in clays in the form of sulphate, or gypsum, with a chemical formula $\text{CaSO}_4 + 2\text{H}_2\text{O}$. When gypsum is heated to a temperature of 370°F ., it loses part of the water forming plaster of paris (CaSO_4)₂, H_2O , a product adapted to many uses, among which is the manufacture of molds for clay wares.

The origin of gypsum in clays is probably the alteration of lime carbonate by sulphuric acid formed by the decomposition of iron pyrites in the clay. It may be present in small crystals or scales visible to the eye, or under the microscope, or it may be so finely disseminated as to be detected only by chemical analysis.

At high temperatures in the kiln the sulphate of lime may be decomposed, forming lime oxide and sulphurous acid, evolved as a gas which in escaping from the ware may form bubbles, blisters, or even cause the product to swell and crack.

Soluble Salts.—A more common trouble is the solution of the sulphate of lime in the water used in tempering the clay, and when the ware is dried, the solution is evaporated from the surface leaving a white deposit of lime sulphate remaining on the surface after burning, as a white-wash.

The coating on the brick at one of the plants in this state was scraped off and analyzed with the following result:

Lime	5.7	per cent.
Magnesia.....	1.34	" "
Sulphur	1.34	" "

1. New Jersey Geol. Survey, vol. VI., p. 64.

Where such a coating proves a detriment to the sale and use of brick, it may be counteracted by adding a substance like barium chloride to the wet clay. This salt will combine with the soluble sulphites of the clay forming the insoluble barium sulphate.

According to Ries¹, a clay containing 0.1 per cent of lime sulphate would require 26 pounds of barium chloride per 1,000 brick, which at two and one-half cents a pound would cost \$0.65. According to this same author 0.1 per cent of soluble salts in a clay is often sufficient to produce a white incrustation.

In the table of chemical analyses of the West Virginia clays, one column gives percentage of soluble salts ranging from a trace to 1.2 per cent. In many of these plants the brick show no white coating even where percentage of soluble elements is high, so that trial alone will show whether this trouble will occur. With the high percentage of soluble salts in some of these clays, there is danger of the white coat showing at some time.

Magnesia.—Magnesia is present usually in only small amount and its effect according to Ries², is to act as a flux, but different from lime causes the clay to soften slowly instead of rapidly, so that the melting and vitrifying temperatures are further apart. Its effect of counteracting the iron to give a buff color to the ware is less than that of lime.

When present in the form of sulphate, it may reach the surface of the ware and form a surface film. Its presence may sometimes be detected by its characteristic bitter taste. The amount of magnesia in different clays, according to Ries³, is shown in the following table:

	Minimum.	Maximum.	Average.
Brick clays	0.02	7.29	1.052
Pottery clays	0.05	4.80	0.85
Fire clays	0.02	6.25	0.513

Magnesia in clays is derived from decomposition of biotite and other magnesian silicates, and also from dolomite, the double carbonate of lime and magnesia. The percentage of magnesium in the West Virginia clays ranges from 0.06 to 2.65 per cent., with an average of 1.28 per cent.

Alkalies.—The most important alkalies present in clays are potash (K_2O) and soda (Na_2O). These have resulted from

1. Geol. Survey of New Jersey, vol. VI, p. 79.
2. New Jersey Geol. Survey, Vol. VI., p. 66.
3. New Jersey Geol. Survey, Vol. VI., p. 67

the decomposition of the silicate minerals which have formed the kaolin. As was shown in the preceding chapter, the base of the feldspar, orthoclase was potash (K_2O) and in its decomposition some of the base may remain in the resulting clay. Potash is also found in the mica, which is often a common constituent of clay. Soda occurs as part of the base of the other feldspars and may occur in the mica.

The alkalis are important fluxing agents, and they determine in a large degree the fusibility of the clay. They are low in amount in the refractory clays and higher in the brick clays. Ries¹ gives their range as follows:

	Minimum.	Maximum.	Average.
Brick clays	0.17	15.32	2.768
Pottery clays	0.52	7.11	2.06
Fire clays	0.48	5.27	1.46

The range in West Virginia, so far determined, is:

	Minimum.	Maximum.	Average.
Brick clays	0.81	6.35	3.16
Pottery clays	1.76	3.89	2.87
Fire clays	0.20	4.21	2.21

In the process of fusion through the agency of the alkalis, the particles of clay are bound together to form a firm mass. In clays low in alkalis, for example, the china clays, feldspar is added as a flux to bind the kaolin particles together through its fusion.

Water—Water exists in clays in two forms, mechanically included or moisture, and water of chemical combination. The mechanical water or moisture is found in the pores of the clay and as surface films around the clay particles. The percentage is variable, and depends on the amount of available water and the fineness of grain. A coarse grained clay does not retain the moisture as readily as a fine grained clay.

When the clay is taken from the bank or mine, the amount of this moisture may reach 20 or 30 per cent, but on exposure to the air, it loses a very considerable portion of the water. At the temperature of boiling water (212° F.) all the mechanical water is driven off and the clay shrinks in volume. This shrinkage, according to Wheeler², varies from 2 per cent. in coarse clays to 10 per cent. in very fine grained clays.

1. Bulletin New York State Museum, No. 35, p. 515.

2. Missouri Geological Survey, Vol. XI., p. 58.

In drying brick clays there still remains a small percentage of this moisture, which is removed in the burning of the kiln in its early stages during the "smoke drying" period. If the temperature of the kiln was high at this stage, the water would be changed to steam, and in escaping would crack the product. The period of smoke drying thus varies according to the thoroughness of the drying of the brick before they are placed in the kiln. The presence of water determines one of the important physical properties of clays, plasticity, as explained later.

If soluble minerals are present in the clay, the water would dissolve portions of them, which would be carried to the surface of the ware in the process of drying and left as films, later appearing as incrustations or discolorations.

The water of chemical combination is present in the clay, especially in the kaolin component, which, when pure, contains 14 per cent. Other hydrous minerals, if present, would also contain water of crystallization.

Since in most clays, the impurities are not hydrous minerals, the percentage of water of crystallization would be less than 14 per cent. The average, according to Wheeler, is 8 to 10 per cent, and in this state runs as low as 4 per cent. in certain sandy clays. The water of chemical combination is removed at a temperature of $1,000^{\circ}$ C., and the clay then loses its property of plasticity.

Titanium.—Titanium is often regarded as one of the rare minerals, yet in microscopic crystals it is not uncommon in granites, and can be seen in thin sections of such rocks when examined under the microscope.

In the decay of the granite, the titanium minerals, especially rutile (TiO_2), would be scattered through the kaolin resulting from the feldspar decay. These minute rutile crystals are not readily weathered or altered, and they would not in many cases give a very high percentage of titanium even in the residual clay, and would yield still less in the transported clay. On account of the low percentage present and the trouble in its determination, most analyses of clay do not show this mineral present.

Titanium determinations were made on the West Virginia clays in the present work, and the amount is usually under one per cent. In two specimens of clay the percentage reached 1.84 and 2.13. In nine clays the percentage was one or more, and

titanium was found in all the clays and shales analyzed, with a range from 0.40 to 2.13 per cent., giving an average percentage of 0.87.

The influence of titanium on clay has been investigated only to a very limited extent, because it has been regarded of rare occurrence and in amount so small that its effect was scarcely worth investigating. The present work of the Survey shows that titanium is far from being a rare impurity in West Virginia clays. Ries¹, has investigated the influence of small percentages of titanium on the fusibility of clays, and finds that the addition of one-half per cent. lowers the fusing point 18° F.; two per cent. lowered it 54° F.; five per cent lowered the point of fusion 108° F., and after fusion all these mixtures showed a deep blue color on fracture.

Phosphorus.—Phosphorus (P_2O_5) is present in all the West Virginia clays examined, though in one-fourth of them a trace only was detected, and in the others, it varied from 0.04 to 1.09 per cent., with an average of 0.316 per cent.

Phosphoric acid is present in granitic and other rocks in the form of lime phosphate, or apatite, which has the following composition²:

	Per cent.
Phosphoric acid (P_2O_5)	40.36
Lime (CaO)	47.60
Magnesium (MgO)	6.08
Ferrous iron (FeO)	1.44
Water	0.11
Chlorine	0.29
Fluorine	6.84

Organic Matter.—Organic matter is present in greater or less amount in nearly all clays, due to vegetable material washed into the clay as it was deposited. This may be irregularly distributed through, or it may form layers giving a banded character to the clay. When present in marked quantity, the organic material may give the clay a dark color, obscuring the coloring effect of the iron.

The effect of this material on the clay in the kiln is not very important where the amount is small. In larger quantities it may add to the temperature of the kiln by its combustion and render

1. New Jersey Geol. Survey, Vol. VI., p. 71.

2. U. S. Geol. Survey, Bull. 220, p. 97, Clarke.

the ware porous, or even crack it. Organic matter burns out at a low red heat.

Carbon of the bituminous type, according to Orton¹, is a troublesome impurity in the clay, as "it is likely to decompose and deposit a fine coke in every pore of the clay, where it can only be burned out with extreme care and plenty of time." If allowed to remain in the clay until red heat is reached, it will reduce the iron, and if not carefully reoxidized, will leave a black core and if reoxidized will have a deeper red color different from the outside.

CHEMICAL ANALYSES OF WEST VIRGINIA CLAYS,

By F. F. Grout.

The following determinations are frequently made on clays, the completeness of the analysis depending on the *purpose* and the *care* of the analyst:

Silica,	Titanium oxide,	Ferrous iron oxide,
Alumina,	Organic matter,	Ferric iron oxide,
Water,		Magnesia,
		Lime,
		Sodium oxide,
		Potassium oxide,
		Manganese oxide,
		Phosphorus,
		Sulphur.

The first group is often considered as *clay substance*, and the purity of the clay is measured by its total. The second group is *neutral* in its action. The third group is classed as *detrimental*, and renders the clay more fusible, though the elements of this group are not of equal value in increasing fusibility.

Some of these determinations give clues to other properties of the clay. Color of the burned ware depends largely on the amount of iron present, especially the ferric oxide, but lime, if present in quantity of three times the iron percentage, may neutralize the color and give a buff shade, if the burning be carried to a temperature of incipient fusion. Shrinkage in burning is due mainly to combined water and organic matter, but is largely counterbalanced by excess of sand, as indicated by a high percentage of silica.

The presence of sulphur trioxide in a clay with lime or magnesium, or both, will give material for the troublesome efflor-

1. Brick, Vol. XX., p. 40, 1905.

escences that appear on some bricks as they dry. The percentage of fluxing components will give a clue to the fire resisting properties of the clay. While the chemical analysis thus throws light on the properties of the clay and its uses, the complete determination of the availability of a clay for various uses should only be made after physical tests are applied.

METHOD OF ANALYSIS.

It is not our purpose to give instruction in the methods of chemical analysis for the use of beginners, as no one should attempt the analysis of clay without some laboratory training. The method used in the present work is practically the same as used by the United States Geological Survey, given in Bulletin 176, by W. F. Hillebrand.

The following outline of the method is given for the information of chemists and others to show how the components of the clay were determined:

Loss on Ignition was determined for the clay instead of the more tedious methods for water and organic matter. In cases where the organic matter was high, an analysis was made similar to a proximate coal analysis, but no non-volatile organic matter has been found.

Silica was separated by double evaporation on the water bath. The weight was corrected by treatment with hydrofluoric acid.

Iron and Alumina oxides, etc., were ignited in the crucible containing the residue from silica. After weighing, the whole precipitate was fused with potassium bisulphate (KHSO_4) and dissolved in five per cent. sulphuric acid for the determination of *titanium*. As the residue from silica usually contained a large part of the titanium, it would be very unsafe to neglect it, or to take an aliquot part of the solution for the determination of iron, alumina, etc.

Iron and alumina were dissolved and re-precipitated only when magnesia was suspected in large amounts. *Manganese* was not determined, as the error is slight and distributed in several places. The clay which gave the highest manganese color in fusion contained 0.15 per cent. of manganese (MnO). *Chromium* was not determined, except in the average where it was less than .004 per cent.

Calcium and Magnesium were determined in the usual way; a single precipitation was usually sufficient. *Barium* was not found in any of the clays tested.

Sodium and Potassium were determined by the J. Lawrence-Smith method. After thorough extraction with water, the fusion was dissolved in hydrochloric acid. Stannous chloride was added to reduce the iron, which was tritrated with permanganate after addition of mercuric chloride and manganous phosphate mixture. Neither the iron nor the alkali determinations were considered satisfactory unless the hydrochloric acid completely decomposed the fusion.

Alumina was determined by difference. *Ferrous Iron* was determined by solution in hydrofluoric and sulphuric acids in an atmosphere of carbon dioxide. Organic matter undoubtedly made some of the results high.

Phosphoric Acid was determined by the acidimetric method. *Sulphur* was determined in the usual way. It was most often calculated as combined in iron pyrites, because the microscope showed this mineral to be present.

RATIONAL ANALYSIS.

Rational analyses have been made in some cases to supplement the ultimate. Such an analysis gives approximate values for *clay substance, quartz and feldspar*.

It is a matter of experience that a mixture of high grade clays, etc., having definite amounts of each of these three constituents, will burn to a constant product no matter what may be the source of the constituents. Thus, if a product is desired from a mixture containing 30 per cent. feldspar, it might be possible to find a clay which already contained 30 per cent. But if not so high, ground feldspar could be added to bring it to the desired point. Or, a clay higher than 30 per cent. might be mixed with one lower than 30 per cent. feldspar. In a similar manner, the percentage of quartz may be regulated.

The rational analysis is of value only in case of the better clays for high grade wares, or refractory material. Even then, intelligent calculation from the ultimate analysis is more accurate. The use of rational analyses is simpler and generally accurate enough for practical work.

The methods are only approximate, and to be of value, should be as uniform as possible, so that the results will be comparable. The method used in the present work is that of W. F. Hillebrand, (U. S. Geological Survey, Bull. 176), which seems to be recommended also by the Agricultural Department (Bureau Chemistry, Bull. 79, p. 52) though their outline appears to be miscalculated.

Strong sulphuric acid and five per cent. sodium hydrate in succession were used to dissolve out the clay substance from the quartz and feldspar. The latter were weighed together and then the *feldspar* was calculated from the alumina ($\times 5.45$) contained in them. The difference in total weight and the calculated feldspar is *quartz*. One hundred per cent. minus quartz and feldspar is *clay substance*. Sometimes "combined silica" is reported, which is simply the difference between the total silica and quartz.

By this method many soluble minerals are dissolved (if present) with the kaolin, and reported as clay substance. The impure clays would thus give deceptive results. In such cases, it is better to calculate the analysis in the following way: All alkalies are combined with alumina and silica in proportions to form feldspar. The remainder of the alumina is combined with silica and water in proportions to form kaolin. Excess silica is reported as quartz, and the other constituents as total fluxes.

The result of such a calculation in the case of clays of higher degree of purity should check closely with the regular rational analysis. In the impure clays, there is little occasion for such a separation. The amount of agreement in these methods is variable but the table below shows a fair average.

MECHANICAL ANALYSIS.

The mechanical analysis reports as clay all the particles below .005 millimetres in diameter. The method used is the centrifugal apparatus recommended for soil analysis by the United States Department of Agriculture.¹

As clays differ from soils in the proportion of large particles, the limits of the groups in the present work have been changed to some extent, though all particles below .005 millimetres are reported as clay. This method of analysis can be made with advantage only on those clays which slake to individual grains after

1. Bureau of Soils, Bull. 24.

shaking thoroughly with an excess of water. This determination will be further considered in Chapter III., under the title "Fineness."

Amount of Clay by the Three Methods.

Specimen Number.	Rational Analysis.	Calculation of Kaolin.	Mechanical Analysis.
4	67.23	52.30	11.8
17	36.80	26.39	36.85
41	72.26	41.65	63.70
62	70.48	41.14	59.70
76	42.41	31.50	33.35

DETERMINATION OF SOLUBLE SALTS.

As an indication of danger of efflorescence coatings, the percentage of soluble salts in the clays has been determined.

The clay was screened through a 40-mesh sieve and heated with water for six hours, then allowed to settle for twelve hours. An amount of the solution representing about two and one-half grams of clay was siphoned off and the dissolved matter determined.

Experiment showed that the time of action of the water altered the results, as did also the addition of any substance to settle the clay particles. The defect of the method rests in the uncertainty that all the particles are well settled. But it gives approximate results, and has been checked in some cases by filtration through porcelain. The composition of some of the soluble salts was determined when the solution was perfectly clear, and found to be unexpectedly high in alumina and silica. In some cases no sulphates could be found.

CHEMICAL ANALYSES.

The following tables show the composition of the various clays of the State, as determined by the method outlined. These have been made in connection with the present investigation of the clay industries of West Virginia, in the laboratory of the Survey.

ANALYSES OF WEST VIRGINIA BRICK AND TILE CLAYS AND SHALES.

TABLE I.

F. F. Grout, Assistant Survey Chemist.

*Shale.

Horizon	Lab. No.	COMPANY.	LOCATION	Silica (SiO ₂)	Alumina (Al ₂ O ₃)	Ferric iron (Fe ₂ O ₃)	Ferrous iron (FeO)	Magnesia (MgO)	Lime (CaO)	Sodium (Na ₂ O)	Potassium (K ₂ O)	Water (H ₂ O)	Titanium (TiO ₂)	Phosphorus (P ₂ O ₅)	Loss on ignition	Total	Soluble Salts
Silurian	58	Tabler farm*	Martinsburg	56.67	19.52	3.06	4.00	1.94	2.23	0.96	3.08	0.36	0.86	0.45	5.56	99.68	....
	59	Lovett Slate Quarry*	Martinsburg	53.30	18.16	1.95	4.58	2.65	4.89	0.82	3.70	0.68	0.72	0.24	7.36	99.82	0.75
	79	Buxton Brick Works*	Martinsburg	57.75	20.17	7.00	0.33	1.22	0.22	0.62	2.59	2.75	0.87	0.09	5.94	99.55	0.28
	60	Red clay over limestone	Bakerton	55.43	18.78	7.06	0.15	2.59	1.56	0.12	0.69	2.62	0.60	0.60	9.13	100.38	0.29
Devon	72	Elkins Brick Co.*	Elkins	58.78	22.57	4.13	1.41	1.00	0.18	0.54	3.15	1.05	1.03	0.35	5.43	99.62	0.23
Pottsville	68	Piedmont plastic clay inside	Piedmont	51.34	29.75	1.65	2.07	0.49	0.31	0.18	1.45	0.98	2.13	0.07	10.22	100.64	0.10
	67	Piedmont plastic clay outside	Piedmont	45.25	33.45	1.79	0.98	0.39	0.17	0.41	2.21	1.52	1.60	0.14	11.67	99.58	0.15
Allegheny	1	Mack Mfg. Co. Lower Etna mine	New Cumberland	57.52	21.76	3.41	3.70	0.88	0.60	0.03	3.57	0.86	0.83	0.14	7.27	100.57	.05
	2	" " " Etna*	New Cumberland	57.89	21.59	5.62	1.26	1.55	0.61	0.29	3.28	1.27	0.72	0.21	6.18	100.47	.10
	11	Clifton mine clay	New Cumberland	52.24	29.28	2.73	0.51	0.20	0.68	0.37	2.11	1.28	1.20	0.07	10.12	100.79	.67
	12	Clifton mine gray rock*	New Cumberland	57.58	21.41	3.75	3.45	1.44	0.46	0.10	3.14	0.38	0.84	0.11	7.25	99.91	.15
	13	Clifton mine blue rock	New Cumberland	59.76	22.79	0.60	3.53	1.23	0.59	0.42	3.79	0.54	0.82	0.46	5.26	99.79	.12
	65	Hammond Brick Co. plastic	Hammond	64.18	22.16	0.83	1.16	0.49	0.42	0.41	2.52	0.53	0.62	0.20	6.15	99.67	.14
Conemaugh	20	Isaacs Ruffner yard upper clay	Charleston	61.92	23.32	0.52	2.86	0.78	0.42	0.27	2.91	1.01	0.40	trace	6.04	100.45	.15
	21	Isaacs Ruffner yard lower clay	Charleston	60.29	23.77	0.27	2.95	1.59	0.54	0.20	3.49	0.56	0.83	trace	5.27	99.76	.10
	74	Hanna farm*	Charleston	54.34	22.01	8.51	0.37	1.47	0.14	0.27	3.08	2.54	0.85	0.22	6.29	100.09	.10
	25	McDonald farm* (Barlow)	Charleston	56.78	22.53	5.24	0.76	1.32	0.68	0.28	3.27	2.27	0.83	trace	6.43	100.39	.13
	24	McDonald farm (Barlow)	Charleston	49.81	33.85	0.68	0.26	0.43	0.36	0.40	1.36	1.38	1.59	0.09	10.30	100.51	.16
	75	Fire Brick Co. plastic clay	Charleston	50.57	30.05	3.43	0.21	0.45	0.68	0.51	2.02	1.55	0.81	trace	9.68	99.96	.44
	63	Thornton Brick Co. plastic clay	Thornton	56.19	26.31	2.82	0.96	1.44	0.39	0.50	3.90	1.39	0.63	trace	5.48	100.01	0.54
	61	Morgantown Brick Co*	Morgantown	55.63	20.76	3.94	4.17	1.70	0.86	0.34	2.97	1.03	0.98	0.23	6.98	99.59	0.38
	4	Bennett farm	Huntington	56.28	22.81	4.69	0.25	0.98	1.37	0.16	1.83	4.07	0.66	0.21	7.16	100.47	0.37
	10(a)	Fourpole creek blue clay	Huntington	46.89	18.04	2.66	1.51	1.70	10.94	0.36	2.88	2.52	0.62	0.44	11.65	100.21	0.03
	10(b)	Fourpole creek red clay	Huntington	47.59	16.51	6.17	1.77	1.87	9.20	0.45	2.86	2.53	0.61	0.62	10.36	100.54	0.10
	30	Huntington Brick Co. blue*	Huntington	58.28	21.26	1.87	3.37	1.35	0.78	0.39	2.87	1.30	0.86	0.39	6.84	99.56	0.46
	35	Clay Shingle Plant buff*	Huntington	58.91	20.00	5.89	1.04	1.75	0.52	0.58	2.22	1.79	0.71	0.64	5.82	99.87	0.06
	37	Clay Shingle Plant red*	Huntington	52.31	22.31	9.17	0.83	1.92	0.62	0.44	2.97	1.58	0.84	0.28	6.56	99.83	0.15
	34	E. Railroad cut buff*	Ona	52.11	23.92	5.28	3.00	2.14	0.36	0.29	2.80	1.61	0.64	0.47	6.91	99.53	0.10
	27	W. Railroad cut buff*	Ona	48.00	25.29	5.34	3.62	2.06	2.33	0.26	3.31	1.60	0.72	0.32	7.41	100.26	0.55
	31	Guan Valley Co. buff*	Barboursville	53.03	22.14	7.12	1.26	1.57	1.01	0.29	3.59	1.94	0.66	0.79	6.56	99.96	trace
	18	Monticello Co.*	Clarksburg	49.69	21.80	4.25	1.43	1.45	5.35	0.23	3.00	3.52	0.72	0.30	8.20	99.94	0.20
	88	Kanaw. & New River Brick Co.	Charleston	51.07	25.78	3.08	3.75	1.26	0.57	0.17	3.27	1.41	1.01	0.14	8.70	100.21	....
Monongahela	19	High Grade Co.*	Clarksburg	56.15	23.48	2.93	0.33	1.55	1.25	0.49	2.66	1.74	0.97	0.38	8.17	100.10	.15
	40	High Grade Co.	Clarksburg	53.35	24.78	1.08	1.66	0.90	4.04	0.24	2.27	1.23	0.86	trace	10.11	100.52	.96
	3	Railroad cut*	Pt. Pleasant	56.48	21.77	4.78	2.61	2.10	0.72	0.46	3.00	1.72	0.83	0.04	6.00	100.51	.10
	7	Camden Brick Co.*	Spilman	50.80	19.47	8.83	1.90	1.74	1.51	0.89	2.24	0.60	0.68	0.20	11.37	100.23	....
	85	Camden Brick Co.*	Spilman	55.29	21.87	5.07	1.69	2.19	0.76	0.55	2.24	1.76	1.02	0.60	6.34	99.38	....
	81	Suburban Brick Co.*	Moundsville	54.52	23.23	4.80	2.23	1.71	0.97	0.53	2.94	1.84	0.82	0.13	5.97	99.69	.25
Dunkard	89	U. S. Tile Co. buff*	Parkersburg	68.42	16.38	3.05	1.89	1.80	0.94	0.63	0.93	0.00	0.88	0.08	4.58	99.58	....

POTTERY CLAYS.

River Clay	76	Donahoe Pottery	Parkersburg	73.33	14.98	1.75	0.24	0.45	0.43	0.29	1.93	1.32	0.81	0.15	4.46	100.14	0.25
	62	W. Va. Pottery (near)	Bridgeport	60.34	20.55	3.53	0.49	1.12	0.38	0.73	2.89	2.35	0.92	0.55	6.42	100.27	1.20
	41	Weas farm	Ravenswood	51.11	20.86	2.87	3.50	2.08	4.19	0.40	3.49	0.95	0.84	trace	9.72	100.01	0.35
	38	Weas farm (upper clay)	Ravenswood	60.90	19.32	6.95	0.50	0.92	0.22	0.31	3.04	1.12	0.84	trace	5.96	100.08	0.36
	190	Randall	Monongalia county	63.32	21.62	1.99	0.37	0.45	0.22	0.18	2.45	2.64	1.12	....	5.54	99.90	....

FLINT FIRE CLAYS

Pottsville	83	Piedmont Brick Co.	Piedmont	61.44	26.18	0.30	0.36	0.04	0.12	0.02	0.00	0.77	1.39	0.01	9.07	99.69	....
Allegheny	66	Hammond Brick Co.	Hammond	43.40	39.55	0.38	0.57	0.13	0.32	trace	0.20	1.03	1.84	0.34	13.12	100.88	0.10
	11	Mack Co., Clifton mine	New Cumberland	52.24	29.28	2.73	0.51	0.20	0.68	0.37	2.11	1.28	1.20	0.07	10.12	100.79	0.67
	191	Deckers creek	Morgantown	46.74	34.05	0.90	0.18	0.37	0.21	0.07	0.17	3.50	2.28	....	12.00	100.47	....
Conemaugh	73	C. Fire Brick Co.	Charleston	53.41	31.38	1.44	0.25	0.06	0.22	0.21	1.03	0.95	1.10	0.31	9.74	100.10	0.13
	87	Kan. & New River Co.	Charleston	54.49	29.94	1.67	0.04	0.18	0.52	0.21	0.17	1.53	1.15	0.26	10.65	100.81	....
	64	Thornton Brick Co.	Thornton	66.69	21.83	0.37	1.00	0.10	0.33	0.08	0.48	0.99	1.11	trace	7.13	100.11	0.12



ANALYSES OF RIVER CLAYS USED FOR BRICK AND TILE IN WEST VIRGINIA.

TABLE II.

F. F. Grout, Assistant Survey Chemist.

	No. Lab.	COMPANY.	LOCATION	Silica (SiO ₂)	Alumina (Al ₂ O ₃)	Ferric iron (Fe ₂ O ₃)	Ferrous iron (FeO)	Magnesia (MgO)	Lime (CaO)	Sodium (Na ₂ O)	Potassium (K ₂ O)	Water (H ₂ O)	Titanium (TiO ₂)	Phosphorus (P ₂ O ₅)	Loss on ignition	Total	Soluble Salts
Ohio Valley	28	Hughes Brick Yard yellow clay.	Barboursville	69.74	14.86	4.75	0.55	0.81	0.36	0.42	2.36	0.99	0.97	trace	4.61	100.42	0.80
	9	Hughes Brick Yard blue clay..	Barboursville	64.65	18.74	1.74	2.20	0.82	0.36	0.41	3.06	1.52	0.68	0.16	5.59	99.93	1.04
	23	Isaacs Yard, Kanawha.....	Charleston	66.89	14.52	5.20	0.59	0.72	0.48	0.71	2.53	1.54	0.77	1.09	4.74	99.78	0.68
	22	Isaacs Yard, Elk.....	Charleston	71.02	13.65	4.69	0.42	0.84	0.59	0.40	2.19	1.15	0.80	0.28	4.23	100.26	0.34
	29	Culloden Brick Yard.....	Culloden	52.89	26.56	4.95	0.59	1.38	0.48	0.20	3.12	1.93	1.00	trace	7.34	100.44	1.00
	26	Heck Brick Yard.....	Milton	68.94	15.13	2.90	1.35	0.95	0.80	0.96	2.24	1.00	0.93	trace	5.31	100.51	0.80
	32	Parkersburg Brick Co.....	Parkersburg	63.38	17.19	5.72	0.50	1.30	0.16	0.60	2.29	1.76	0.87	0.36	5.60	99.73	0.60
	36	Copen Brick Works.....	Parkersburg	70.00	13.70	4.53	0.42	0.94	0.38	trace	2.97	0.97	0.79	0.37	4.77	99.84	0.27
	5	Hess Brick Yard.....	Pt. Pleasant.....	65.97	16.61	4.84	0.42	0.53	trace	0.63	2.17	2.04	0.78	0.06	5.60	99.65	0.54
	80	Magnolia Brick Co.....	New Martinsville...	65.35	15.47	6.48	0.29	0.63	0.23	0.71	2.59	2.08	0.84	0.31	4.93	99.91	0.77
	39	Grosscup Yard.....	Buckhannon	78.12	11.55	3.23	0.34	0.40	0.26	0.14	1.32	0.78	0.46	trace	3.50	100.10	trace
	16	Coffman Yard.....	Clarksburg	73.46	12.29	3.90	0.33	0.95	0.28	0.41	1.57	1.78	0.74	0.59	4.26	100.56	0.50
	78	Kingwood Brick Co.....	Kingwood	66.08	16.15	5.75	0.37	0.87	0.17	0.31	2.43	1.17	0.80	0.17	5.64	99.91	.33
	17	Weston Brick Yard yellow clay.	Weston	75.01	12.15	3.65	0.23	0.68	1.45	0.15	1.39	1.45	0.55	trace	3.90	100.61	.17
	8	Weston Brick Yard red clay...	Weston	69.67	15.45	3.61	0.50	0.92	0.14	0.36	1.40	2.00	0.95	trace	4.53	99.53	.17
Potomac Valley	33	Devine farm.....	Hurricane	55.66	24.10	2.42	1.66	1.54	1.02	0.41	3.75	2.09	0.96	0.27	6.34	100.22	.25
	77	Jefferson Brick Co.....	Charles Town.....	54.35	21.49	8.00	0.00	0.79	0.30	trace	6.35	1.62	0.86	0.09	5.70	99.55	.10
	84	Ridgely Bros.' Yard.....	Ridgely	74.86	11.01	5.31	0.18	0.29	0.40	trace	1.54	1.07	0.76	0.44	4.07	99.93	....
	86	Snyder farm.....	Martinsburg	70.41	10.20	7.11	0.45	0.58	0.50	0.37	1.73	1.82	1.20	0.26	5.05	99.68	....

TABLE III.
Brick and Tile.PHYSICAL TESTS ON WEST VIRGINIA CLAYS AND SHALES.
F. F. Grout, Assistant Survey Chemist.

*Shale.

Lab. No.	Company	Location	Water required	Air shrinkage	Tensile strength, lbs.		Plasticity	Incipient Fusion				Vitrification				Complete Fusion				Range Vitrification to Viscosity °F.
			%	%	Not weathered	Weathered	Number	Cone	Temp. °F.	Color	Fire shrinkage, %	Cone	Temp. °F.	Color	Fire shrinkage, %	Cone	Temp. °F.	Color	Fire shrinkage, %	
79	Buxton Brick Works*	Martinsburg ..	28	4	122	150	20	03	1994	red	10	02	2030	red	11	5+	2246+	red	12	216+
72	Elkins Brick Co.*	Elkins	25	3½	39	83	15	02	2030	red	2	1	2102	brown	10	5+	2246+	black	11	1444+
67	Piedmont Brick Co.	Piedmont	18	.....	.....	.....	16	30	3146	brown	2	.....	.....	.....	.....	.....	.....	.....	.....	.....
1	Mack Mfg. Co. Etna...	New Cumberl'd	26	3½	39	68	17	02	2030	brown	3	3	2174	red	..	5+	2246+	brown	10	72+
2	Mack Mfg. Co. Etna*	" "	27	4	36	71	15	1	2102	red	2	3	2174	red	4	5+	2246+	red	8	72+
11	Mack Mfg. Co. Clifton.	" "	28	4	58	96	15	.....	.....	.....	..	26	3002	gray	2	28	3074	gray	2	.....
12	Mack Mfg. Co. Clifton.	" "	24	4	39	85	17	1	2102	red	5	4	2210	brown	6	.....	.....	.....	.....	.....
13	Mack Mfg. Co. Clifton.	" "	26	4	46	110	15	03	1994	buff	3	1	2102	.....	4	5+	2246+	brown	6	1444+
65	Hammond Brick Co.	Hammond	20	3½	58	100	21	.....	.....	.....	..	14	2570	buff	10	20	2786	buff	10	216+
20	Isaacs Ruffner yard...	Charleston ..	29	4	79	105	9	1	2102	buff	4	5	2246	.....	..	15	2606	.....	..	360
24	McDonald farm	Barlow	18	6	54	104	15	14	2570	brown	2	27	3038	black	3	.....	.....	.....	.....	.....
25	McDonald farm*	" "	25	6½	97	140	14	02	2030	pink	8	2	2138	red	11	5+	2246+	black	12	108+
75	Fire Brick Co.	Charleston ..	26	6	112	157	10	20	2786	cream	2	.....	.....	.....	..	27	3038	gray	3	.....
74	Hanna farm*	" "	30	6	100	133	10	02	2030	red	5	1	2102	red	6	5	2246	red	..	144
63	Thornton Brick Co.	Thornton	24	4	89	151	24	02	2030	buff	4	1	2102	brown	6	5+	2246+	brown	6	144+
61	Morgantown Brick Co.*	Morgantown ..	22	4½	109	141	18	02	2030	red	1	1	2102	red	2	5	2246	black	..	144
4	Bennett farm	Huntington ..	27	8	212	275	12	04	1958	red	6	1	2102	.....	..	10+	2426+	brown	10	324+
10	Fourpole creek	" "	20	.....	.....	.....	..	04	1958	red	..	.....	.....	.....	..	1	2102	black	..	144
30	Huntington Brick Co.*	" "	25	4½	78	131	10	02	2030	gray	5	3	2174	gray	7	5+	2246+	black	7	72+
35	Clay Shingle Co.*	" "	27	3½	70	136	10	04	1958	red	1	02	2030	red	8	5+	2246+	black	12	216+
37	Clay Shingle Co.*	" "	29	8	175	208	10	05	1922	red	1	02	2030	red	8	5+	2246+	black	10	216+
27	West R. road cut*	Ona	24	6	126	168	16	05	1922	red	2	02	2030	gray	3	5+	2246+	black	..	216+
34	East R. road cut*	" "	25	5½	94	134	11	04	1958	red	..	02	2030	red	..	5	2246	brown	10	216
31	Guyan Valley Co.*	Barboursville ..	25	4½	78	131	10	03	1994	red	2	1	2102	red	2	5	2246	black	..	144
18	Monticello Brick Co.* ..	Clarksburg ..	21	5	53	83	18	05	1922	red	4	1	2102	red	5	5+	2246+	red	5	144+
19	High Grade Brick Co.* ..	" "	23	5	132	180	16	02	2030	buff	4	5	2246	buff	5	.....	.....	.....	.....	.....
40	High Grade Brick Co.	" "	20	6	157	218	20	02	2030	cream	4	1	2102	gray	7	5+	2246+	.....	8	144+
85	Camden Clay Co.*	Spilman	29	4½	88	152	11	03	1994	red	7	1	2102	red	11	5+	2246+	black	12	144+
81	Suburban Brick Co* ..	Moundsville ..	25	4½	102	117	11	04	1958	red	1	02	2030	red	10	5	2246	red	12	216

FLINT FIRE CLAYS.

83	Piedmont Brick Co.	Piedmont	21	3	32	38	4	36	3362	white	2	..	.....	.....	..	.....	.....	.....	..	.....
66	Hammond Brick Co.	Hammond	18	3	35	48	4½	36+	3362+	gray	2	..	.....	.....	..	.....	.....	.....	..	.....
11	Mack Mfg. Co. Clifton.	New Cumberl'd	15	4	58	96	15	.....	.....	.....	..	26	3002	gray	2	28	3074	gray	2	72+
73	C. Fire Brick Co.	Charleston ..	25	4	63	85	20	36	3362	cream	..	..	.....	.....	..	.....	.....	.....	..	.....
87	Kan. & New River Co.	" "	26	2½	34	38	6	27	3038	white	4	31	3182	white	4	.....	.....	.....	..	.....
64	Fire Brick Co.	Thornton	20	3½	75	114	3	.....	.....	.....	..	30	3146	gray	..	.....	.....	.....	..	.....

POTTERY CLAYS.

76	Donohoue Pottery	Parkersburg ..	25	6	264	286	19	1	2102	cream	3	5	2246	cream	3	10	2426	cream	4	180
62	Willis farm	Bridgeport ..	25	6	187	215	14½	02	2030	buff	7	1	2102	brown	10	5+	2246+	brown	10	144+
41	Weas farm, lower	Ravenswood ..	30	5½	154	190	11	04	1958	red	8	02	2030	brown	10	2	2138	brown	11	108
38	Weas farm, upper	" "	29	5½	150	202	14	02	2030	red	5	1	2102	red	5	5+	2246+	black	5	144+

TABLE IV.

PHYSICAL TESTS ON WEST VIRGINIA RIVER CLAYS.

F. F. Grout, Assistant Survey Chemist.

Lab. No.	Company	Location	Water required	Air shrink-age	Tensile strength, lbs.		Plasticity	Incipient Fusion				Vitrification				Complete Fusion				Range Vitrification to Viscosity °F.
			%	%	Not weath-ered	Weath-ered	Number	Cone	Temp. °F.	Color	Fire shrink-age, %	Cone	Temp. °F.	Color	Fire shrink-age, %	Cone	Temp. °F.	Color	Fire shrink-age, %	
28	Hughes yard, buff.....	Barboursville ..	28	5	201	201	18	02	2030	pink	4	1	2102	gray	4	5+	2246+	black	11	144+
9	Hughes yard, blue.....	" ..	25	4½	152	160	11	02	2030	red	2	1	2102	red	5	5	2246	black	..	144
23	Isaacs yard, Ruffner...	Charleston ...	28	5	155	155	13	1	2102	red	8	....	.....	.....	..	6	2282	red	..	.....
22	Isaacs yard, Elk.....	" ..	28	4½	112	130	16	1	2102	red	7	4	2210	red	9	8	2354	black	..	144
29	Culloden yard.....	Culloden	31	8	170	180	10	02	2030	red	7	3	2174	red	15	5+	2246+	red	15+	72+
26	Heck yard.....	Milton	23	4½	120	165	19	01	2066	red	2	1	2102	red	..	5+	2246+	red	..	144+
32	Park. Brick Co.....	Parkersburg ..	32	6	140	145	13	03	1994	red	4	02	2030	red	6	5+	2246+	red	12	216+
36	Copen yard	" ..	27	4½	200	222	18	02	2030	red	3	1	2102	red	5	5+	2246+	brown	9	144+
5	Hess yard.....	Pt. Pleasant...	32	4½	183	183	14	02	2030	red	2	1	2102	red	7	5+	2246+	red	8	144+
80	Magnolia Co.....	New Mart'sv'le	25	4½	191	201	11	02	2030	gray	6	1	2102	gray	6	5	2246	gray	8	144
39	Grosscup yard	Buckhannon ..	23	4½	86	113	10	5	2246	red	8	10	2426	red	..	14+	2570	red	..	144+
10	Coffman yard	Clarksburg ...	24	4½	179	210	20	2	2138	gray	3	5	2246	gray	7	....	.....	.....	..	.....
78	Kingwood yard.....	Kingwood	26	4	121	132	21	3	2174	red	8	6	2282	red	10	10	2426	red	..	144
17	Weston yard, buff.....	Weston	23	....	..	..	..	2	2138	pink	6	5	2246	gray	9	10	2426	.....	..	180
8	Weston yard, red.....	" ..	..	....	..	..	..	02	2030	pink	7	1	2102	gray	8	5+	2426+	black	10	144+
33	Devine farm	Hurricane	24	5½	122	202	12	03	1994	buff	3	1	2102	brown	5	5+	2246+	brown	5	144+
77	Jefferson Brick Co....	Charles Town.	32	8	53	167	19	02	2030	red	5	1	2102	red	8	5	2246	black	..	144
84	Ridgely yard.....	Ridgely	19	3½	83	99	17	3	2174	red	4	5+	2246+	red	..	....	.....	.....	..	.....
86	Snyder farm	Martinsburg ..	29	5	151	170	16	02	2030	gray	6	1	2102	gray	6	5+	2246+	gray	10	144+



CHAPTER III.

THE PHYSICAL PROPERTIES OF CLAYS.

Knowing the composition of the clay as revealed by chemical analysis and the role of the chemical compounds, the value of the clay as a useful product for certain purposes can be approximated. But with this information alone, the knowledge of the true value of the clay would be quite incomplete, and might lead to troublesome and expensive errors.

Clay capable of utilization in the works of man must possess certain physical properties, some of which can be foretold by the chemical analysis, while other properties must be determined in a different way, by a series of physical tests. A discussion will now be given of the following physical properties of clays :

- | | |
|----------------|-----------------------|
| 1. Color. | 8. Plasticity. |
| 2. Odor. | 9. Bonding Power. |
| 3. Taste. | 10. Tensile Strength. |
| 4. Feel. | 11. Slaking. |
| 5. Fracture. | 12. Fineness. |
| 6. Fusibility. | 13. Porosity. |
| 7. Shrinkage. | 14. Specific gravity. |

I. COLOR.

The color of clay varies from white through gray, yellow, brown, red, to black. Color is usually determined by the nature of the iron compounds and amount of vegetable matter present. If much of the latter impurity is present, the clay will be gray or even black in color. The iron compounds give the brighter colors, and when both iron and vegetable matter are absent, the clay is usually white, though a pure white clay may still contain iron in small quantity, or in larger quantity neutralized by other mineral substances.

It is not always possible to predict the color of the burned ware from that of the unburned clay. A red clay will usually burn into a red ware. A blue clay may burn red or even buff.

Dark colored clays with color caused by organic matter will have this impurity removed by heat, and the color will then be determined by the composition of the clay.

The color of the ware, determined by the iron percentage, as has been shown in the preceding chapter, will vary with the temperature used in the kiln, and in the nature of the kiln atmosphere, whether it is oxidizing or reducing. In the West Virginia clays, a wide range of colors may be found, but the most common shades are yellow or buff, red and blue.

The color of the burned ware will depend on the chemical composition of the clay and the physical conditions involved in the burning. Iron alone under ordinary conditions gives a red color to the burned ware, but the color will be influenced by the amount of iron present and by the presence of other elements which neutralize the iron color. Seger¹ divides clays into four groups of colors for the burned ware determined by chemical composition of the crude clay.

1. Clays high in alumina and low in iron burn white or to a scarcely noticeable color.

2. Clays high in alumina and containing moderate amounts of iron give colors ranging from pale yellow to buff.

3. Clays low in alumina and high in iron, the brick clays burning red.

4. Clays low in alumina and high in iron and lime, the brick clays burning red.

In the third group, according to Seger, if the amount of alumina is not over three times the iron, the ware will have a good red color, but if the alumina be $5\frac{1}{2}$ or more times the iron, the color will be brown to yellow.

MANGANESE COLORED BRICK.

In recent years there has been a demand for brick of special colors and speckled brick for fronts of buildings or trimmings. Red and buff burning brick clays are changed into the desired colors by the addition of manganese, a mineral found in certain parts of the country, which may be obtained from chemical dealers at no great cost.

In practice one part by weight of manganese is mixed with nine parts of clay and tempered with water to make a slip known as the stock stain nearly black in color. Experiment will show

1. The Collected Writings of Herman Seger (Amer. Translation), Vol. I., p. 109, 1902.

how much of this stain to add to the clay in the pug mill to secure the desired result. Red brick clays can be used with manganese forming brown brick. Buff burning clays will make gray brick by addition of the manganese.

Speckled brick are made by the use of granulated manganese mixed with the clay in the form of soft mud, and then added to the clay in the pug mill in a proportion determined by trial. A very slight increase or decrease in percentage of manganese will affect the color. One-fourth of one per cent. will make a noticeable change in color.¹

In this State, the Isaacs Brick Company, of Charleston, has produced some very artistic brick by use of manganese, but this is the only plant making ornamental shades, and much of the product used in the northern part of the State comes from Ohio.

2. ODOR.

Clays have a characteristic earthy odor, made more prominent in the presence of moisture. This is more noticeable in some clays than others, and it is popularly considered a test of purity, but odor is not a safe guide to the quality of a clay.

3. TASTE.

Clay has a peculiar earthy taste, and adheres more or less closely to the tongue. If the clay is plastic, the particles will adhere together and form a pasty mass in the mouth. If sand or grit is present, it will be detected by the teeth, so that a rough calculation may be made of the character of the clay whether it is sandy or not. Certain soluble impurities, like alum, salt, magnesium sulphate, iron sulphate, etc., may be detected by the taste.

4. FEEL.

Fine grained kaolins are smooth or soapy to the touch; all clays have this same feel to a greater or less degree, so that they are sometimes spoken of as soap-stone. The same name is applied to the shales, since they show this same property when wet. True soapstone, or talc, is quite a different substance from clay.

Sand may also be detected in the clay by working it between the fingers, and some clue to plasticity is given by working the

1. This information on use of manganese has been kindly furnished by Kendall & Flick, Washington, D. C., dealers in high grade manganese.

wet clay with the hand and noticing whether it can be readily fashioned into shape.

5. FRACTURE.

The high grade fire clays when broken show a series of shells, known as the shelly or conchoidal fracture, while other clays have the earthy fracture, breaking in a more irregular manner.

6. FUSIBILITY.

Fusibility, or the change from the solid state to a liquid condition, becomes an important property in clays for economic use. Every mineral in a pure state and under uniform conditions has a definite fusion temperature.

Clay being usually impure, composed of kaolin and a number of additional compounds, would have varying fusion points for its different components, so in burning a clay fusion of the particles takes place at different temperatures, producing different results. This makes fusibility in clays a very complex subject. It is difficult to follow the reactions and interactions in a clay under high temperatures. Certain components almost infusible in themselves are fused in the presence of other compounds. The fusion point of two intermingled compounds may be lower than the fusion point of either one taken by itself.

Lime and quartz are regarded as almost infusible, but together act as a flux. A mixture of the carbonates of sodium and potassium fuses more easily than either salt.

The three important points of fusion in the process of clay manufactures are given by Wheeler¹ as the points of incipient fusion, vitrification and viscosity. At a certain temperature, some very fusible portions of the clay will begin to melt and cement together the unfused portions, forming a fairly compact mass. This stage is that of *incipient fusion*. Ordinary brick are not carried far beyond this point.

As the temperature is raised, other less fusible components melt and fill the pores of the product, making a dense, firm mass, and this point is that of *vitrification*. If the heat be further increased, the various components of the clay may melt and the mass begin to flow and alter the shape of the product, the clay having now reached the point of *viscosity*.

1. Missouri Geol. Survey, Vol. XI., p. 130.

To illustrate the range in the above temperatures, the Albany slip clay was tested by Ries¹, who found the point of incipient fusion at 1700° F., vitrification at 1850° F., and viscosity at above 2000° F. The American fire clays of high grade fuse, from 3146° F. (1730° C.) to 3326° F. (1830° C.).

In some very fusible clays the difference between incipient fusion and viscosity is less than 100 degrees, while in other clays it may reach 500 or 600 degrees. The amount of this difference is important, for in burning a kiln of ware, it is difficult to control the temperature within narrow limits of range. If the difference in temperature is small between vitrification and viscosity, it will be difficult to vitrify the brick without melting the whole mass.

The temperature of fusion of a clay will depend on the porosity, chemical composition, amount of fluxes, kind of fluxes, and size of particles. In the porous clay the particles will be removed from each other so that the heat conductivity will be lowered.

The chemical composition of the clay, in addition to the fluxing impurities has an influence on its fusibility. The experiments of Bischof and Richters in Germany, as quoted by Seger, lead to the following conclusions:

1. The degree of refractoriness of clays depends on the ratio which the fluxes bear to the refractory elements, silica and alumina.
2. The various substances that act as fluxes exert a fluxing influence in the ratio of their combining weights.
3. The same amount of fluxes exerts a greater fluxing action on the clay when it is high in silica than when it is high in alumina.
4. If the alumina be very low, it acts as a flux.

The nature of the fluxes will have an effect on the temperature of fusion. According to Wheeler² the alkalis are more fusible than ferrous oxide, which is more fusible than lime, and lime is more fusible than magnesia. Also a mixture of bases is more fusible than one base.

The size of the particles in the clay will influence the temperature of fusion, as the smaller particles will fuse more readily,

1. Bull. N. Y. State Museum, No. 35, p. 808.

2. Missouri Geol. Survey, Vol. XI., p. 146.

and the smaller size particles will decrease the amount of pore space, especially when there is a variety of sized particles, the smaller particles filling in spaces between the larger ones.

METHODS OF MEASURING FUSIBILITY.

The temperature of fusion of a clay may be determined by a pyrometer, or by using test pieces, such as the Seger cones. The former is a thermo-electric instrument which measures the current generated in the thermo-pile placed in the kiln or retort. The wires are connected with a galvanometer, which measures the electric current generated and gives the temperature. The objections to the use of this instrument have been the delicacy of adjustment and resulting care made necessary in its manipulation, and the high cost (\$160).

The use of test pieces in the form of Seger cones for determination of temperature in burning of clays, is rapidly increasing. These cones are about two inches high, made of kaolin, feldspar, quartz, marble, and iron oxide, etc., so mixed as to fuse at different constant points, but a few degrees apart in temperature. A group of these cones after fusion is shown in the lower part of Plate II.

The original series of Seger was numbered from 36 down to 1, giving a range of fusion temperatures from 3322° F. (1850° C.) to 2102° F. (1150° C.). Later a more fusible series was added below 1 and numbered by the prefix of a cipher (0) to each number, giving a series from 1 down to 022, with a fusion point of 1094° F. (590° C.), melting at a low red heat. The cones in this series are only 20° C. apart, except in twelve, which are 30° apart (022 to 010).

In use, a number of cones are placed with the clay to be tested, and the fusion point of the clay in question determined by comparison with the fused cone whose temperature of fusion is known. The melting point of the cone is reached when its tip bends over and touches the base. When used in the clay working plants, the cone representing the temperature desired for burning the ware is placed in the kiln, and also a few cones of lower fusing points, so that they may give warning of approach to the desired temperature.

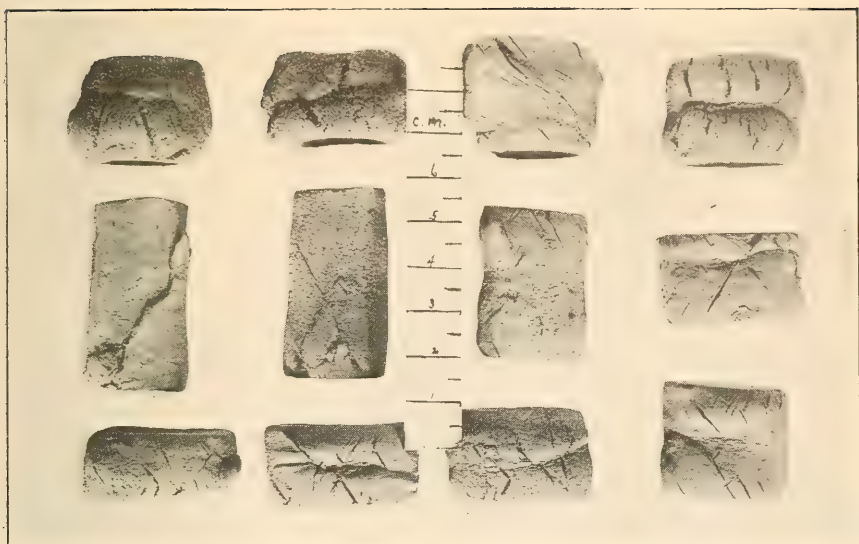


Plate II-a.—Clay Cylinders Compressed in Grout Method of Measuring Plasticity.

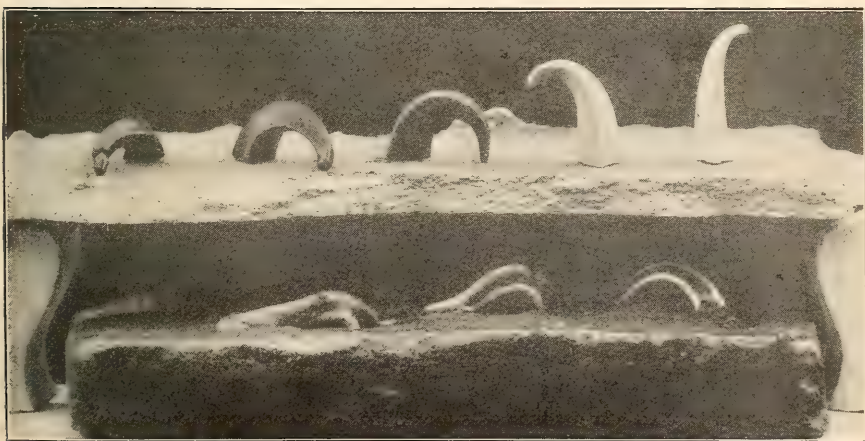


Plate II-b—Seger Cones, Showing Effect of High Temperatures.

The following table¹ gives the numbers and fusion points of the Seger cones:

Number of Cone.	Fusing Point. °F.	°C.	
022	1094	590	
021	1148	620	
020	1202	650	
019	1256	680	
018	1310	710	Dull red heat.
017	1364	740	
016	1418	770	
015	1472	800	
014	1526	830	
013	1580	860	
012	1634	890	Cherry red heat.
011	1688	920	
010	1742	950	
09	1778	970	
08	1814	990	
07	1850	1010	} Clear cherry red heat.
06	1886	1030	
05	1922	1050	
04	1958	1070	
03	1994	1090	
02	2030	1110	
01	2066	1130	
1	2102	1150	} Deep orange heat.
2	2138	1170	
3	2174	1190	
4	2210	1210	
5	2246	1230	
6	2282	1250	
7	2318	1270	
8	2354	1290	
9	2390	1310	White heat.
10	2426	1330	
11	2462	1350	
12	2498	1370	
13	2534	1390	
14	2570	1410	Bright white heat.
15	2606	1430	
16	2642	1450	
17	2678	1470	
18	2714	1490	
19	2750	1510	} Dazzling white heat.
20	2786	1530	
21	2822	1550	
22	2858	1570	
23	2894	1590	
24	2930	1610	
25	2966	1630	
26	3002	1650	
27	3038	1670	
28	3074	1690	

1. The temperature color effects as well as the table are taken from Ries' reports.

Number of cone.	—Fusing Point—	
	°F.	°C.
29	3110	1710
30	3146	1730
31	3182	1750
32	3218	1770
33	3254	1790
34	3290	1810
35	3326	1830
36	3362	1850

The series may be obtained from Seger and Cramer, at Berlin, at a cost of about 2½ cents each, including duty and express. The cones from 010 to 35 can be obtained from Prof. Edward Orton, Jr., Ohio State University, Columbus, Ohio, at one cent each.

7. SHRINKAGE.

The term shrinkage refers to the loss of volume on drying, or *air shrinkage*, and the loss of volume on burning, or *fire shrinkage*. When the clay is dried the water is evaporated from the pores and partly from around the clay particles, which thereby draw together, causing the product to shrink in volume, and this contraction is called air shrinkage. If the clay is dried rapidly the surface moisture will be removed before that on the interior and later the interior moisture passing out will crack and check the ware through the unequal contraction. If a high temperature is applied to the wet clay, the water in the pores may be changed into steam, which expanding will crack or shatter the clay.

On heating the clay to higher and higher temperatures, the product will shrink through the removal of the remaining water around the clay particles, the water films, the removal of organic matter, the chemically combined water, and later by the fusion of compounds in the clay which then flow out and fill the pores, rendering the mass compact. This contraction is known as fire shrinkage. If the heat is applied too soon, the ware may be cracked by the expansion of water in the interstices or by the unequal expansion of the clay components. Some clays will shrink greatly at a low temperature, causing them to twist and crack to such an extent that they are worthless, unless other materials of low fire shrinkage are added to lower the shrinkage of the mixture.

The presence of silica in the form of quartz or sand, if not in a finely ground state, gives a more open texture to the clay.

While such a clay may hold a considerable percentage of water in the open spaces, its removal will be accompanied by very little shrinkage, so that air shrinkage is lowered by such sand mixture. Silica in itself being almost infusible, its addition to the clay will also decrease the fire shrinkage. Grog or burned clay wares broken and ground may be added with the same results.

It is important for the manufacturer to determine the amount of air and fire shrinkage in order to secure a product of correct and uniform size. The dies must be made sufficiently large, so that the burned clay ware after shrinkage may have the desired form and size.

DETERMINATION OF AMOUNT OF SHRINKAGE.

Shrinkage may be expressed as volume shrinkage or as linear shrinkage. The latter is usually adopted, but varies in a given mass with the dimensions, and the surface exposed to evaporation. In the present work, shrinkage has been determined¹ on a molded briquette 3x1x1 inches, and the average shrinkage of the three dimensions taken. The briquettes were frequently turned in the process of drying, and the final results represent an average of several test pieces.

8. PLASTICITY.

Plasticity is the property whereby a substance may be molded or modeled. When applied to clays it also involves the further property of retention of the given form after the molding or modeling process is completed. In clays this property is only developed in the presence of water.

CAUSE OF PLASTICITY.

Various theories have been advanced to account for plasticity in clays, but the real cause still remains a matter of doubt and speculation.

I. One of the older theories regards the chemically combined water as the cause, since plastic clays heated to redness, where this water is removed, become non-plastic and the former plasticity cannot be renewed.

Against this theory is the fact that other hydrous silicates with chemical combined water equal in amount to certain plastic

1. By F. F. Grout.

clays show very little plasticity. Many non-plastic clays contain a higher percentage of combined water than certain plastic clays. In fact, as Wheeler¹ pointed out, there are so many accompanying changes in the clay at high temperature that there would be no special reason for selecting the loss of chemically combined water as the all-important one. The clay changes color, takes on increased hardness and strength, and finally becomes entirely changed in its physical as well as its chemical nature.

2. Pure kaolin clays are often non-plastic, while the plastic clays are usually impure through the addition of various foreign ingredients. This fact early suggested the cause of plasticity to be the presence of these impurities.

There are pure kaolin clays, however, which are plastic and many so-called non-plastic kaolin clays become plastic when finely ground or when weathered. The presence of impurities is more apt to lower the plasticity than to produce it.

3. Because certain non-plastic clays become plastic when finely ground and because the fineness of clays appears to increase plasticity, the cause of this property has been ascribed to fineness of the clay particles.

Other non-plastic clays show no plasticity, even when finely ground, and other mineral products show no special degree of plasticity when so ground.

4. Haworth, in a microscopical examination of the clays of Missouri, found vermicular, or hooked, crystals, which by interlocking might explain the plasticity, and especially the strength of form after the clay was molded.

But even in these clays where the crystals were most abundant, plasticity was not well developed, and in some other very plastic clays these crystals were absent. In clays from other regions such crystals appear to be of rare occurrence.

5. G. H. Cook, of New Jersey, long ago called attention to the presence of plate-shaped particles in clays as a clue to the cause of plasticity, and the work of the Missouri Survey seemed to show that the shape and amount of such plates present were very important in determining plasticity, and Wheeler² concludes that "the fine plate, or minute scale theory, seems to most satis-

1. Missouri Geol. Survey, Vol., XI., p. 99.

2. Missouri Geol. Survey, Vol. XI., p. 103.

factorily explain the plasticity of clays and other lamellar minerals."

6. One theory regards plasticity as depending on the amount of kaolin mineral present, but some clays high in kaolin are non-plastic, and many clays low in kaolin are very plastic.

7. According to Ladd¹, the mutual attraction between water and clay particles, and surface tension of the water films around the clay particles exert an important influence in determining plasticity.

8. Recently the colloid theory has been advanced to explain the cause of plasticity. It is claimed that in plastic clays, a small proportion of particles is found which soften and become sticky under the action of water. These colloid (glue-like) particles mixed with the mineral particles are thought by some writers to form one cause of plasticity.²

In forming a satisfactory working theory of plasticity, it seems that most of these theories contain partial explanations, and that a combination of these will afford a very plausible explanation. The combination theory would define a plastic clay as one composed of finely divided plates or scales, held together by mutual attraction and water film tension, aided by colloids, if present.

When water is added to the plastic clay, it fills the open pores and spreads out between the clay plates or scales surrounding these with a surface water film. The high surface tension of these films would hold the particles together, though permitting them to slide on one another, and the strength of this tension would depend on the nature and size and shape of the particles.

On drying the moisture would pass out from the pores before the surface films would be broken and as the water was further evaporated from the films, they would decrease in size drawing the clay particles closer and closer together. When these particles were brought into close contact, the mutual attraction of the particles if of suitable size and shape would hold them together more or less closely. If not of suitable size and shape, when the

1. Geol. Survey of Georgia, Bull. No. 6-A, p. 31.

2. N. J. Geol. Survey, Vol. VI., p. 83 (Ries.)

U. S. Depart. Agriculture, Bureau of Chemistry, Circular No. 17, p. 5 (Cushman).

water film was finally broken, the particles would fall apart and the mold crumble.

In the plastic clays plate-like particles occur, while they seem to be less abundant or absent in the so-called non-plastic clays. When certain non-plastic clays are weathered or are ground, the plate-like particles are developed and the clay becomes plastic. It would thus appear that the plate shape was the proper one to hold the particles together. This shape gives the greatest surface and would enable the particles to come in close contact over a larger area.

DEGREE OF PLASTICITY.

The higher the degree of pasticity, the more easily the clay particles slide over each other and the more strongly they are held together by mutual attraction of particles, so that the clay can be molded into a great variety of shapes with very little care in manipulation, producing a ware more or less perfect in shape and durable in form.

All finely ground substances show this property of plasticity to a greater or less extent. Fine sand shows a very low degree of plasticity. It can be molded when wet, but not in very good shapes without breaking, and the form is not durable. Certain clays show a very high degree of plasticity and are called plastic clays. Plastic clays are found to vary in degree of plasticity according to the percentage of water added. They reach a maximum degree of plasticity with a given percentage of water, which percentage varies in different clays. According to Wheeler¹ this maximum plasticity is developed by the following range in percentage of water in the different types of clays:

	Per cent.
Loess or brick clays.....	16.0 to 19.0
Fire and potter's clays	15.0 to 33.0
Flint clays	15.0 to 24.0
Kaolins	18.0 to 35.0
Shales	14.0 to 25.0

DETERMINATION OF PLASTICITY.

Plasticity being such a valuable property of clays, it is important to determine whether a clay is plastic or not, and also to form an idea of the amount of plasticity. A method of accurately

1. Missouri Geol. Survey, Vol. XI., p. 98.

measuring plasticity would be most valuable and so far has not been discovered, though various attempts have been made in this direction.

The practical clay worker takes a piece of clay and works it up with water in his hand and determines by the feel or the ease with which it works whether the clay in question is highly plastic or fat, slightly plastic or lean, or non-plastic. This method is easy of manipulation, but it is crude; and while it gives the practical worker an approximate idea of the character of the clay, it or any other method depending on a man's judgment would not be available for comparison with other clays tested by different persons.

Bischof¹ suggested a method of "making into sticks a series of mixtures of a standard plastic clay with variable amounts of fine sand, and then rubbing them with the finger over sheets of paper and observing the amount of dust rubbed off. The clay to be compared is then similarly rubbed over other sheets of paper, and it is rated with that member of the standard series which rubs off in about equal amounts, or with equal readiness."

Another method suggested by Bishof consisted of forcing plastic clays through a horizontal or vertical die into the shape of narrow cylinders and determining their length before breaking by their weight.

Langenbeck² used the proportion of water necessary to bring a clay to the proper consistency for molding, as a measure of plasticity. The proper consistency was attained when a Vicat needle with a weight of 300 grams penetrated the clay to a depth of four centimeters in five minutes. The work of the South Carolina Survey showed that by the use of this method all but three of the clays of the coastal plain were of "good" plasticity. But Ries in his work on the Michigan clays found examples where 19 per cent of water was required for a clay of low plasticity, and 17 or 18 per cent for another of high plasticity.

Ladd³ used two metal boxes with test tube brushes in them so placed that when the boxes are placed end to end the brushes nearly touch. Dry clay is sifted in the boxes and allowed to ab-

1. Die feurfesten Thone, p. 88, quoted Mo. Geol. Survey, Vol. XI., p. 109.

2. Chemistry of Pottery, p. 19.

3. Geol. Survey of Georgia, No. 6-A., p. 52.

sorb moisture through the perforated bottom of the boxes until the clay is saturated. One of the boxes is rigid and the other mounted on wheels. Weights are added so as to pull the movable box until the wet clay breaks apart between the brushes. This would indicate the tensile strength of the wet clay and thus was thought to be a measure of plasticity.

Wheeler¹ on the Missouri Survey made briquettes of wet clay which were dried and then broken in a testing machine, and the tensile strength of the dried clay as thus determined is regarded also as a measure of the plasticity. The more plastic the clay, the greater its tensile strength when dry, according to this method. Careful tests on different types of clay fail to prove this relation to be constant enough for the determination of plasticity.

If the clays could be molded in wet condition into briquettes and these could be removed without injury to the briquettes and broken carefully in an easily adjusted machine, the tensile strength of the wet clay could be determined and thus, it is said, be a measure of plasticity. So far it has been almost impossible to overcome the mechanical difficulties in this method.

In the work on the West Virginia clays, Mr. F. F. Grout, assistant chemist of the survey, has used a very satisfactory method of measuring plasticity, and he thus describes his work:

METHOD OF DETERMINING PLASTICITY.

By F. F. Grout.²

None of the methods for obtaining a numerical measure of plasticity, as far as recorded, give uniform and accurate results. Most of these methods are based upon misconceptions of the nature of plasticity. One prominent mistake is to consider tensile strength of the molded clay when dry as a measure of plasticity as illustrated by the work of Wheeler in Missouri. Plasticity is a property of clay in the wet condition. Any extensive series of tests shows how tensile strength of the dried clay differs from plasticity (see work of Georgia, Maryland, Iowa, and New Jersey surveys).

1. Missouri Geol. Survey, Vol. XI., p. 111.

2. Part of this work has been published in the Sept. number of *Journal, American Chemical Society*, 1905.

Ries¹ mentions that air shrinkage varies with plasticity, but follows that statement with tests where, for example, a shrinkage of five and one-half per cent is found in a lean clay² but one of the highly plastic clays had a shrinkage of only four per cent. He diagrams air shrinkage and water required. There seems to be no connection between them and certainly neither vary as to plasticity.

Plasticity may be considered as involving two variable factors: 1. Amount of possible flow before rupture; 2. Resistance to flow or deformation. Plasticity increases in direct proportion to each of these factors and is therefore equal to their product.

Bischof's method of forcing a pencil of clay through a die might be used as a measure of resistance to flow, but the distance to which the pencil could be projected without breaking would measure neither resistance to flow nor amount of flow. The Vicat needle as used by Lagenbeck, and the balanced plumb bob used in the Georgia clay investigation would measure only the resistance to flow. They offer no opportunity to measure the amount of flow before rupture. Martens in his handbook of "Testing Materials" gives a mathematical expression for plasticity which depends on toughness and the elastic limit. These two factors are determined by complex formulae, and the method is too complicated for practical work.

In the present work the two factors of amount of flow and resistance to flow were determined by simple methods, and these results are made available for comparison by using the product of the two factors as a *measure of plasticity*. In making these tests compression methods were used in preference to tensile, because in practice, clay wares are subjected more to compressive than tensile strain. This is especially true in brick clays which are compressed in the auger brick machine, in the stacks of brick in the drying tunnel and in the kiln, and finally in actual use in buildings or pavements.

1. Michigan Geol. Survey, Vol. VIII., Part I., p. 5.

2. Ibid, p. 22.

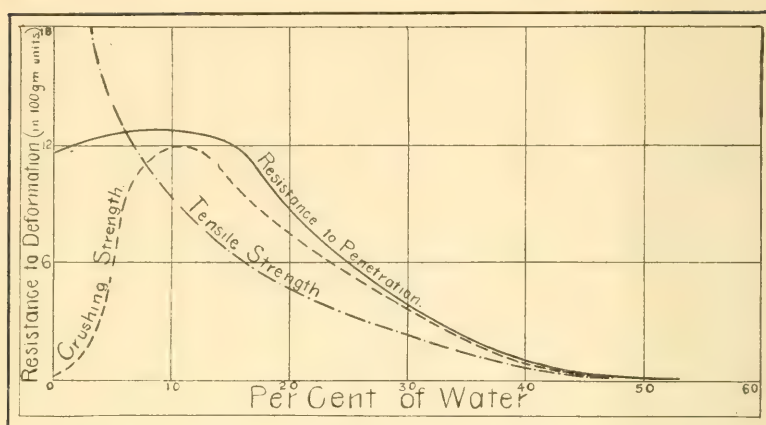


Figure 1.

The various methods of measuring the strength of a clay as it dries, give curves of the same general form through the interval in which the clay is appreciably plastic, that is with 10 to 35 per cent of water, as is illustrated in figure 1. The tensile strength curve was made from figures given in the clay report of the Georgia Geological Survey.

In the determination of the two factors given above, the clay was molded into a variety of shapes and compressed and the results noted. It was found that cylinders gave the most uniform results and were comparatively easy to produce with uniform texture. The upper part of plate II. illustrates the compression changes in the clay cylinders in this method of determination of plasticity. In these experiments, which were performed on a small scale, the clay was carefully mixed and tempered and then forced into a thin-walled metal cylinder, three-fourths (2 c. m.) inch in diameter. A plunger forced the clay through this die and the cylinder was cut into two inch (5 c. m.) lengths. These small cylinders were placed vertically under a movable plate which could be loaded with weights as desired. The amount of pressure, measured in hundred grams, necessary to compress the cylinder one-half centimeter was taken as the measure of *resistance to flow or deformation*. The average of several readings was taken and located on a cross section diagram where the abscissas represent the percentage of water added, and the ordin-

ates represent the amount of compression in centimeters. This experiment was repeated with different percentages of water and the curve plotted as shown by the dotted line in Figure 2.

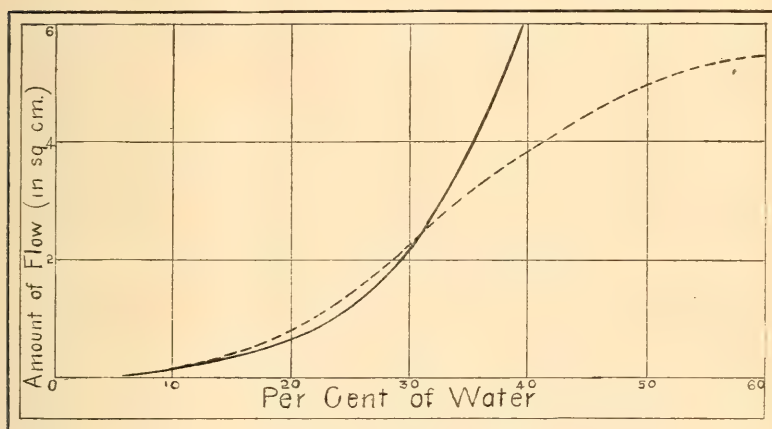


Figure 2.

After the above readings were taken, each cylinder was compressed to the point of fracture. The first appearance of cracks at about 45 degrees to the vertical line was considered as indicating the point of fracture. In this experiment vertical cracks, due to tension as the cylinder expanded, were disregarded, and an irregular swelling of the cylinder under the pressure was an indication that the mass was not uniform. The distances the plates descended before fracture were used as ordinates and the curve plotted as shown in the dotted line in Figure 2.

Since the amount of flow varies from zero to *infinity*, the increase in area of the head of the cylinder was taken as a measure of the *amount of flow*. These measurements were plotted and gave the curve shown by the full line in Figure 2. The two lines thus plotted vary but little from each other until the distance and increase in area reach two and one-half centimeters. The point of maximum plasticity in all the clay tested falls below that point, so it would make but little difference which line was used to measure the amount of flow.

A combination of the two curves of resistance to flow (Figure 1, dotted line) and amount of flow (Figure 2) would give the curve of plasticity. This is illustrated in Figure 3, which includes

the results of tests on different clays and with different percentages of water added. The highest point in a curve represents the point of *maximum plasticity* of that clay.

The method outlined above for the determination of resistance to flow does not always give uniform results though the outlines of some of the curves showed that the averages were fairly close. To overcome these defects, a more accurate method was found in the use of the Vicat needle. To avoid the friction on the sides of the needle, a needle seven square millimeters ($\frac{1}{8}$ inch) was used and the weight determined which was necessary to cause the needle to sink three centimeters into the clay in a half minute. The results of this test are shown in the curve rep-

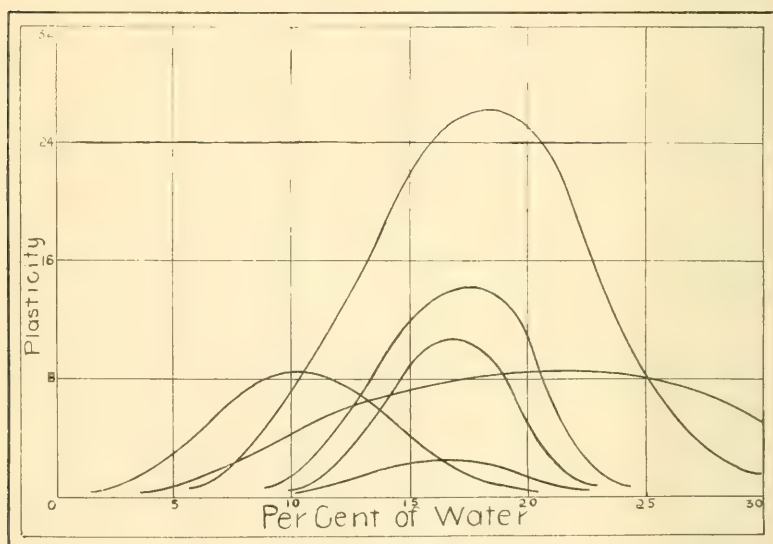


Figure 3.

resented by the full line in Figure 1, where the clay and the conditions were the same as used in the determination of the dotted line. The variation in the two curves is at one end only, and that where the water percentage was low and the clay therefore too dry to be appreciably plastic.

Figure 4 will illustrate the method used in the determination of the curves represented in Figure 3. The broken line is the

curve showing amount of flow, and the dot and dash line is the curve of resistance to flow. The product of these two factors is represented by the solid line, which is the curve of plasticity.

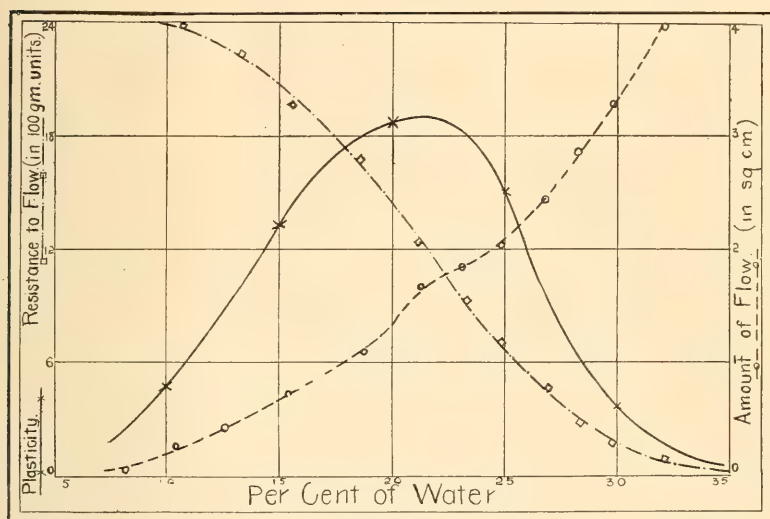


Figure 4.

In preparing the clays for these tests, they were ground so as to pass through a 40-mesh sieve. One hour was allowed for tempering the clay after the water was added. The mass was thoroughly mixed each time a cylinder was filled and the two determinations of amount of flow and resistance to flow were made in rapid succession. In using the Vicat needle a cylinder five centimeters in diameter and four centimeters in depth was filled with a pressure of about one hundred pounds, and the excess clay struck off with a spatula. The loaded needle was released just at the surface of the clay. The compression of the cylinder for determination of amount of flow required three or four seconds of time. In all of these tests the temperature was kept as near 20° C. (68° F.) as possible. In using this method about fifteen clays can be measured in eight hours. Results range from 1 to 30 for lean and plastic material, respectively.

In applying this method to a very considerable number of clays, no examples were found where a lean clay gave a higher maximum plasticity than a more plastic one. It is possible by

this method to compare the plasticity of clays of different types and shales. The results, while not absolute, are serviceable for comparative purposes.

RESULTS OF EXPERIMENTS.

The following experiments give a general idea of the results of our laboratory work on plasticity:

(1) *Fineness*.—Shale No. 63, at 40-mesh, had a plasticity of 14. At this time about 50 per cent. of it was fine enough to pass a 100-mesh sieve. A duplicate was ground to pass 100-mesh, when the plasticity was 18. Shale No. 64 rose from 3 to 7 by similar treatment. Shale No. 40 gave the reverse result, dropping from 18 to 16. This was unexpected, but has been found true in other cases. The majority improve, some are unchanged and a few are injured a trifle.

It has been shown¹ that addition of sand injures plasticity directly as the diameter of grains increases. Clay No. 16 had a plasticity of 17; mixed with an equal weight of sand at 40-mesh the figure was 7; with sand at 100-mesh, 9. Several shales were only slightly affected by 25 per cent. sand, while others were seriously injured. This was probably due to the presence of some sand in the original clay, so that a small addition brought the total sand to a high per cent. The grinding of minerals not considered plastic gave the following figures:

Quartz at 100-mesh.....	2
Calcite at 100-mesh.....	3
Muscovite at 100-mesh.....	4

These figures are in excess of those obtained by our regular method applied to some flint clays.

(2) *Shape of Grain*.—The above experiment with powdered minerals is full of meaning in this connection. Microscopic work revealed the presence of abundant plates in many clays, but no definite results can be stated.

(3) *Colloids*.—Under this head we may discuss the effects of weathering (though the relation to colloids is doubtful), and the effects of adding colloids to clay; incidentally, also, the staining of colloids, their strength when dry, and power of hydration.

All clays, tested thus far, improve in plasticity by a few days'

1. Beyer and Williams, *Iowa Geol. Survey*, Vol. 16, p. 86.

alternate wetting and drying. Weathered river clays show very little change compared with shales. The extreme case was shale No. 64, which rose from 2.6 to 14 in two weeks. Air-drying did not destroy the improvement. The shales ground to 40-mesh weathered to approximately the same figures as the duplicates at 100-mesh. This suggested that the action might be largely mechanical. The amounts of clay (below 0.005 mm.) in shale No. 63 were determined before and after weathering. The per cent. rose from 7.7 to 17.8 by one wetting and drying. Shale No. 63 was also used to test the action of bacteria. One of three samples of the clay was sterilized with chloroform in a bottle plugged with cotton. The chloroform was removed by thorough evaporation under diminished pressure. Sterile water was used in weathering, and great care was taken to prevent any addition of bacteria. The second sample was weathered with city water (Monongahela River), and dried in open air. The third was kept dry. In a week they were tested.

Sterile weathered shale, plasticity..... 18

Ordinary weathered shale, plasticity..... 18

Unweathered shale, plasticity..... 14

It is certain, however, that bacteria can live in clay, and probably do add protoplasm to it; hence, organic colloids, which may increase plasticity in some cases. So much emphasis has been placed on weathering, in the discussion of colloids, that further light was sought, in the determination of combined water before and after weathering. After two weeks' weathering and large increase of plasticity, three samples were air-dried for twenty-four hours. Hygroscopic moisture varied from the original, some increasing, some decreasing. But when calculated to 100 per cent. without this free water, the combined water checked very closely with the original unweathered clay (0.02 per cent.). The amount of combined water in a clay does not change with rise of plasticity. An increase was noted in the soluble salts. Possibly the sulphides were oxidized, or the mechanical action exposed more surface to the solvent.

Two experiments will illustrate our results in adding colloids to clay. Two distinct types of substances were used, colloidal solutions and gelatinous precipitates.

A very dilute solution of the agar-agar of bacteriologists was used instead of water in tempering two clays of plasticity equal

to 7 and 11. The figures were increased to 11 and 15, respectively, by as small an addition of agar as 0.08 per cent. of the weight of the clay. The addition of 0.2 per cent. caused a further increase, but not in proportion to the amount added. Now one of the great objections to the colloid theory is "the very small and inconsiderable proportion of ingredients which are capable of assuming the colloid state by the action of water alone."¹ It will be noticed that 0.2 per cent. is an inconsiderable amount which produces an effect well worth considering. Further, agar has a gelatinizing effect ten times as strong as gelatine, another colloid. It is conceivable that some substance may be even more active than agar, so that a few hundredths of a per cent. may increase plasticity remarkably. After the agar was added, the samples were air-dried, gently crushed to 40-mesh, and the plasticity measured. It was as high as when agar was first added. Ten grams of the air-dried samples were heated with water and settled for a determination of the soluble salts. It was supposed that the presence of a colloid would be noted in that determination. *No jelly could be obtained.* To further test for the presence of a soluble colloid the whole sample was washed with hot water on a porcelain filter for two days. Its plasticity was unaffected. The same was true for a plastic clay (No. 16) which had not been treated with agar.

Alumina-cream was washed by decantation and used without drying, instead of tempering water. It required an amount (measured as Al_2O_3) equal to 3 per cent. of the weight of the clay to raise the lean clay (7) as much as 0.08 per cent. agar (11). The mass was then air-dried, powdered and the plasticity measured. It had dropped to the original figure (7). Weathering a week increased it less than half a point. As plastic clays are not thus injured by air-drying, it is evident that such colloids as alumina-cream do not explain plasticity. Some colloid is required which will soften in water after air-drying, and these are extremely rare in the inorganic kingdom. The suggestion of some recent writers², that a hydrated silicate of alumina could be precipitated so as to give the desired properties, has been carefully tried, but all resulted exactly as the alumina cream. Most of the silicate was prepared by mixing sodium silicate and alum solutions.

1. Beyer and Williams, Iowa Geol. Survey, Vol. 16, p. 90.

2. A. S. Cushman, Trans. Am. Ceramic Soc., 6.

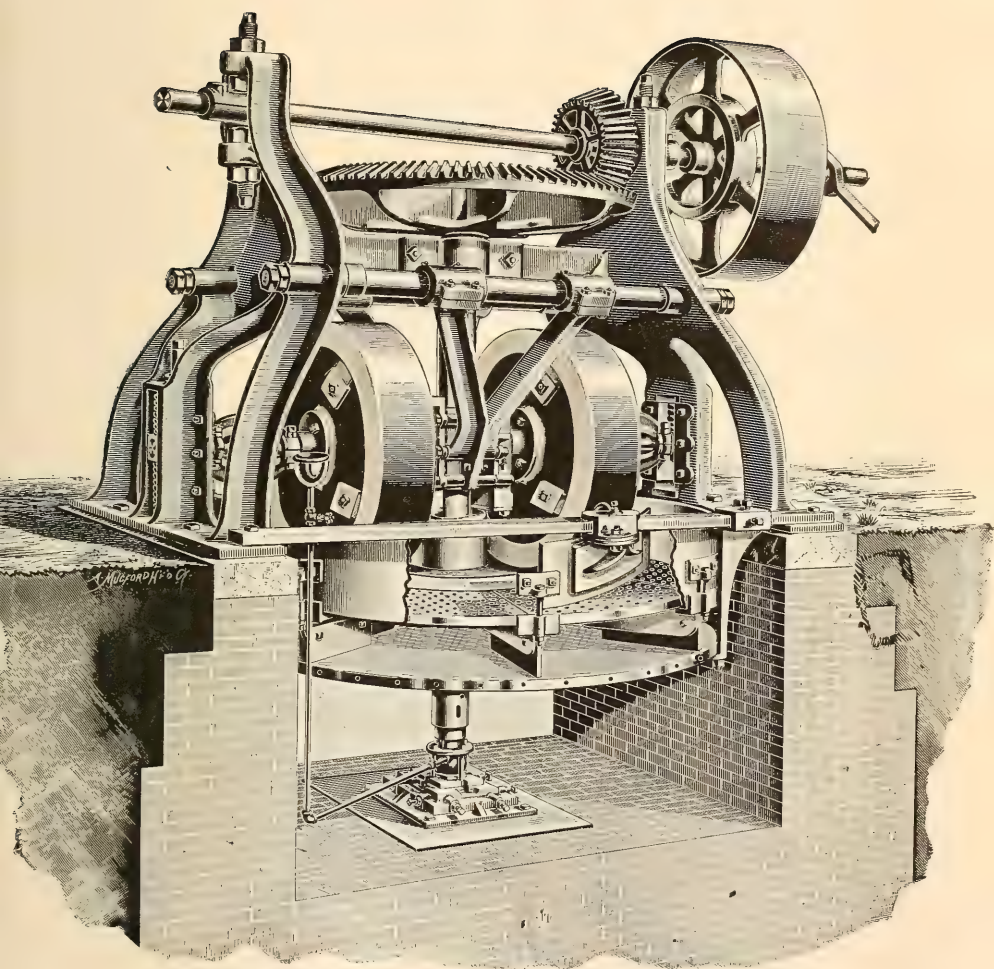


Plate III.—Stevenson Dry Pan for Crushing Clay.

both of which are supposed to occur in clays as decomposition products of other minerals. No precipitate was obtained which would appreciably soften after air-drying. The assumption that some unknown silicate of alumina possesses such a property is unjustified by the known properties of inorganic colloids.

The fact that colloids are stained by methylene-blue has recently been presented in the discussion of colloids.¹ I find that most clays contain from 1 per cent. to 5 per cent. of grains which will take a stain from methylene-blue, gentian violet, eosin, or fuchsine. These might be classed as colloids or "pectoids," though their exact nature is undetermined. For, I find much organic matter will take such stains; freshly gelatinized silicic acid will stain easily; *air-dried silicic acid jelly will take the stain with equal readiness*. Now, air-dried silicic acid has an action *identical with angular quartz sand* in affecting plasticity of clay, injuring, instead of causing plasticity. Some clay grains which stained very little showed a border or spot of color, agreeing with the idea that the production of this form, capable of being stained, is due to some secondary action. But weathering, with its remarkable increase in plasticity, does not materially increase the number of grains taking the stain, nor the depth of color. The observation of "minute spherical particles, which may be of colloidal character,"² thus loses some importance. The fact that they are amorphous does not necessitate softening in water. In this connection, a recent writer³ has found that high magnification reveals crystalline structure in the "globules" of Zettlitz kaolin, which have long been considered amorphous.

The value of strength tests, in discussing colloids, is indirect. Plastic clays are often strong. Colloids added to a powder, often increase its strength. Hence, it is argued, colloids are in clay. But the conclusion is not inevitable. Colloids, like air-dried silicic acid, *decrease* strength, and in studying the substances which *increase* it, we find that not only colloids like agar, but crystalloids like gypsum and alum, are quite active.

The absorption of hygroscopic water is another indirect argument. Clays absorb water. Colloids absorb water. Hence, it is said, clay contains a colloid. But it may be a colloid like dried

1. A. S. Cushman, U. S. Dept. Agr. Bur. of Chem., Bull. 92.

2. H. Ries, New Jersey Geol. Survey, Vol. VI., p. 83.

3. S. Kasai, Z. Kryst. Min., 1899, p. 653.

silicic acid, so that nothing is indicated in connection with plasticity. The colloid structure is admittedly destroyed by ignition, but we have found some thoroughly ignited clays which absorbed water in amounts quite comparable with un-ignited clay, after standing in moist air.

CONDITIONS OF A PLASTIC CLAY.

After a little kneading, each grain in a mass of clay is wet on all sides by a film of water. Of course, if the grains are angular and the water is not abundant, or if the pressure is considerable, the adjacent grains may penetrate the film and come in direct contact. But through some force—call it capillarity, or surface tension, or some other—the water spreads in films around the grains. The cohesion of water, the adhesion of clay grains and water, and the cohesion of clay through the water films, unite to make the moist clay hang together. At the same time the water films act as lubricants. This combined cohesion and lubrication form the ultimate basis of plasticity. A simple illustration is the action of two glass plates with water film between. When dry, friction is great and cohesion small, both in case of the ground clay and the glass plates. As water is added friction decreases till no greater than that of the liquid. Cohesion meanwhile becomes large, just as enough water is added to wet the surfaces, and then steadily decreases when excess of water is added.

Plasticity, as defined above, will depend on two factors: first, the *distance* the clay particles can move on each other without losing coherence; and second, the *amount* of that coherence, or the resistance to movement. Under the first factor we find that the distance will vary with (*a*) the shape and size of grains and with (*b*) the distance through the film that they will attract each other. Under the second factor we find the resistance to deformation will depend on (*c*) the friction in the films and (*d*) the friction of the grains on each other, as they become irregular and penetrate the film.

(*a*) It is evident that two plates $2 \times 2 \times \frac{1}{4}$ inches will glide farther without losing coherence than two blocks $1 \times 1 \times 1$ inch, though the bulk is the same. Again, angular grains may cohere, but relatively small movement will cause a separation, due to the

rough surfaces, that coherence becomes inappreciable. Again, two blocks 1x1x1 inch could be extended into a coherent mass of much greater length if the blocks were subdivided. Fineness also increases the surface exposed, requires more water, and thus improves lubrication.

(b) The attraction of two clay grains may vary with the nature of the grains. The greater the attraction, the farther they can be separated without losing coherence. This will be discussed presently in detail.

(c) The film may produce more friction to gliding in several ways. It may become greater in area. The friction of two plates $2 \times 2 \times \frac{1}{4}$ would be four times as great as two blocks 1x1x1. Again, the film may become viscous. The action of colloids is probably at this point. Another way in which the films become viscous is the result of molecular attraction, which *binds* a film over the surface of the grain and renders it viscous.¹ The thinnest films are most viscous. The friction between this film and the solid grain of clay is said to be infinite, compared with water outside of the film². But when forced to move the resistance would depend on the strength of the attraction of clay and liquid.

(d) It is evident that wet rough sandstone will exert more friction than wet polished glass.

Twice in the above summary of the possible variations in a clay, I have referred to molecular attraction. This is yet to be justified. The extremely small range of its influence seems to render it insignificant. Quincke finds that glass attracts water in this way for 0.00005 mm. Other men and methods give results of the same order of magnitude, this figure being the one quoted by the text-books. Now a simple calculation, based on the mechanical

1. Dr. Ladd (Georgia Geol. Survey, Bull. 6-A.) mentions that the "mutual attraction" of clay and water is so great that it gives a certain "rigidity" to the water, thus giving strength to a clay when it is so wet one would expect it to be quite fluid. But he gives no data to show that this cause is sufficient to produce the results mentioned. In fact, he refers mainly to capillarity (p. 21), whereas, the rigidity is to be found only in the sub-capillary films. He further attributes the "pull" to chemical composition (p. 31), which we will consider later. Beyer (Iowa Geological Survey, Vol. XVI., p. 97) also speaks of the physical attraction of particles for the surrounding one through a film of water, but he fails to note the effect on viscosity, and the fact that attraction may differ, with different substances.

2. Daniell, Alfred: "A Text-book of the Principles of Physics," 3rd Ed., Macmillan Co., p. 306.

analyses of clays, will show¹ that the amount of water needed to place a film 0.00005 mm. thick around each grain is often nearly equal to the amount added in tempering. So that in ordinary plastic clay, it is necessary to consider practically all the water as being under this influence. Any variation in viscosity or in thickness of the films seems to be beyond the region of experiment. The quantity is too small to admit the determination of slight changes, but such are constantly assumed in physical problems. W. J. A. Bliss,² speaks of clay particles and the surrounding adherent liquid, as follows: "*The thickness of this shell depends on the intensity of the attraction between the solid and the liquid.*" J. E. Mills,³ says, "*molecular attraction depends primarily on the chemical constitution of the molecule.*" This is the essential fact of our theory. Some hydrous silicate of alumina attracts and holds a thicker film of water in a viscous condition than most powders. Another factor besides the constitution of the solid is the quality of the liquid. Slight amounts of soluble salts in the water will change the attraction. W. J. A. Bliss, in the above mentioned article, suggests this explanation for the coagulation of suspended clay particles and the reverse effect by other salts.

The molecular constitution on which this theory rests is not to be confused with composition. Kaolin may or may not be plastic. Amorphous varieties have been appealed to in explaining the variation in kaolin, but this may not be necessary. Dr. F. W.

1. Our mechanical analyses frequently show a large per cent. of grains below 0.001 mm. in diameter, also from 0.001 to 0.005 mm. The average diameter of grains below 0.001 mm. is 0.0005 mm. If these are considered spherical and of specific gravity 2.5, it would require 25.5 per cent. by weight of water to place around each grain a film 0.00005 mm. thick. If the grains were considered plates one-fifth as thick as wide, instead of spheres, over 54 per cent. of water would be required. Then in an average "fine clay," 40 per cent. of water will produce only sub-capillary films. A similar calculation for the clay from 0.001 to 0.005 mm. in diameter shows that it would require 8 per cent. Thus many of our clays requires 25 per cent. of water to produce these films.

2. Phys. Rev., Vol. 2, 373, (1894-5).

3. J. Phys. Chem., 1902, p. 209.

Clarke suggests¹ seven possible formulae for crystallized kaolin; two being more probable than others. Our suggestion is that at least *two exist*. Similar changes are suggested² to account for changes in the physical properties of other silicates, *e. g.*, orthoclase and microcline. In the case of kaolin, we may therefore imagine a change in physical properties, due to the chemical constitution of the molecule, but considerable experimental work has not suggested wherein the constitution varied, nor how one might hope to obtain the desired form.

In the light of this theory, our experiments may be interpreted as follows: Sand injures plasticity little at first because the grains are suspended in a plastic mass. It is only when grains are abundant enough to come in contact with their neighbors, that the effect becomes serious, and then both strength and amount of possible flow are injured. Certain rare organic colloids increase the plasticity by rendering the water viscous. Fineness also tends to increase plasticity. Plane surfaces (plates) increase the amount of possible flow. They also give a chance for lubrication by thinner films, thus increasing the friction of film, and the strength of the whole mass. The action of plates is thus two-fold; but fineness may be carried to such an extent as to break up plate-like grains into angular fragments. The beneficial effects of plates are also decreased by the fact that each is so closely surrounded by others in the mass. Molecular attraction is two-fold in increasing plasticity. As the attraction increases, the coherence and strength

1. In U. S. Geol. Survey, Bull. 125, Dr. Clarke recommends the formula: $\text{Al-OH} (\text{SiO}_4)_2 \text{H}_2 (\text{SiO}_4)_2 \text{Al}$. The kaolin, however, is a very stable compound, and, as he suggests, the group— $(\text{SiO}_4)_2 \text{H}_2$, is doubtful. The stability also favors a more symmetrical arrangement. In quite an extensive series of tests in our laboratory no difference was found in the ease of extracing the atoms of any one element of the kaolin. Comey's "Dictionary of Solubilities" refers to Malaguti as authority for the extraction of one-fourth of the silica by potassium hydroxide. We could not confirm this. Sulphuric acid, bromine, chlorine, and ammonium chloride, if used at a temperature and concentration to attack kaolin, will do so progressively, and, in the end, completely. We therefore favor the formula $\text{Si}_2 \text{O}_5, 2\text{Al} (\text{OH})_2$, credited to Groth. The diorthosilicate is also symmetrical, $\text{Si}_2 \text{O}_7 \text{H}_4 (\text{AlO})_2$; but the group $\text{Si}_2 \text{O}_7 \text{H}_4$ —should be open to the same objection as the group— $(\text{SiO}_4)_2 \text{H}_2$. Several other complicated symmetrical formulae can be imagined, but the simplest, most symmetrical is the dimetasilicate of Groth's. The trisilicate offers the most evident opportunity for isomeric salts, but does not offer a symmetrical arrangement. This, of course, does not affect the evidence found in the relation of the kaolin to other silicates, which led Dr. Clarke to recommend the first formula mentioned.

2. Van Hise, U. S. Geol. Survey, Mon. XLVII., p. 202.

of the mass increases, and the amount of possible deformation before crumbling also increases. Fineness increases this action by requiring more water. Colloids and crystalloids in solution may also increase the attraction. It is thus seen to be more active than any other single factor.

SUMMARY.

(1) Plasticity is stated to be a double property involving strength and possibility of flow.

(2) A method is given for measuring plasticity.

(3) The causes suggested for the high degree of plasticity in clay (including fineness, thin plates, colloids), and the effect of addition of sand, have been tested, quantitatively, and found insufficient.

(4) A theory is proposed which bases the cause of plasticity on cohesion and adhesion, and suggests that the high plasticity of some clays is due to the greater attraction of those grains for water. As it is shown that such an attraction depends on the *constitution* of the molecule, any change in the chemical constitution affords a reasonable explanation of the fact that clays of definite composition may vary in plasticity. Composition must be distinguished from molecular constitution.

CONCLUSION.

Molecular attraction depending on the chemical constitution of molecules is the chief cause of the high degree of plasticity found in clays. But practical work in improving clays¹ may well follow the lines already started: first, the addition of such colloids as tannin, etc., or such solutions as ammonia, alum, etc., which can be shown by experiment to produce the desired results; and second, weathering, with its mechanical action and its possible addition of colloids by bacteria.

1. The tendency for tensile strength to vary with plasticity is also easily explained in this way. Molecular attraction between two kaolin grains may be high. If the attraction for water is high, some water will be drawn between the grain and rendered viscous by the attraction; this makes plasticity high. But when the water dries out from such a mass, the kaolin grains still attract each other, and the chances are for greater strength than when wet, because the water has acted as a lubricant, allowing a readjustment of grains to fill the space left as the water moved out. The result is a high degree of consolidation.

9. BONDING POWER.

Plasticity is a property of wet clay which permits it to be molded, while bonding power has a double significance, the retention of form when dry, and the ability to unite with foreign materials. The more plastic the clay, the better it retains its form, also the more plastic the clay, the more foreign materials can be added to the clay. While the two properties of plasticity and bonding power are different, they usually stand in close relation, and in some definitions of plasticity the two are confused when plasticity is defined as the property of clay whereby it may be molded and retain the form when dry.

The bonding power is an important property to be determined in the utilization of clays in order to know how much foreign material can be safely added to the clay. In the manufacture of fire brick from non-plastic clays, it is necessary to add a plastic clay in sufficient amount to hold together the particles of the non-plastic clay so it can be molded and retain its molded form until burned. Sand or grog may be added to plastic clays of high shrinkage to counteract such a defect. In this case, it is important to know how much sand must be added and whether this quantity will seriously injure the bonding power. The coarser the sand, the more it injures the tensile strength, as shown by Orton.

The bonding power might be measured by adding a certain definite percentage of Standard sand to different clays and comparing their tensile strength; or it may be determined directly by the tensile strength of neat (without sand), dried, clay briquettes. The tensile strength of clays, which has been regarded by some investigators as a test of plasticity, is better a test of the bonding power. This is illustrated by the fact that some clays of high plasticity have a low tensile strength, and others of low plasticity have been found with high tensile strength.

10. TENSILE STRENGTH.

As has been stated in the preceding sections, plasticity is said to be measured by the tensile strength of the wet clay; and bonding power, by the tensile strength of the dried clay.

The method of making tensile strength tests is practically the same wherever clays are tested, and is the method devised for testing cements, adapted to clay work. The briquettes of clay are

molded in brass molds and are about three inches long by one and three-quarters inches wide at the ends, tapering to the center, where the area of the cross section is one square inch.

In testing clays to determine their tensile strength, it is difficult to secure uniform results on account of the personal factor involved in the mixing and molding of the briquettes, so that tests made on the same material by the same person will vary, but this variation should be kept within as narrow limits as possible. The tensile strength of clays varies from almost nothing to several hundred pounds. Ries¹ gives the range of tensile strength in different types of clays as follows:

	Maximum.	Minimum.
Kaolins	20	60 Pounds.
Fire clays.....	0	150 "
Brick clays.....	50	300 "
Pottery clays.....	50	250 "

In making the briquettes of West Virginia clays,² the material was ground so as to pass a 40-mesh sieve, then mixed with water to bring it to a good working consistency. In order that comparable results could be obtained it was necessary that one person mold the briquettes and keep the consistency of the clay and the manner of filling the molds as uniform as possible.

Practical brick makers have stated that the dried brick were stronger if molded quite wet. The work of the Iowa Survey (pp. 83-4) seems to indicate the reverse. In our own work, we find that other factors have much greater influence than the variation of water content. The clays for the tensile strength tests were kept wet for about one hour, then thoroughly wedged and roughly shaped to the molds, into which they were pressed by several light blows with the bare hands. The excess clay was struck off with a spatula, and the molds were lightly oiled to facilitate removal.

On account of the variability of results it was necessary to test several briquettes and use the average. Three to twelve briquettes of a kind were used. To determine the effects of some slight weathering a briquette was made from each clay after the powdered clay had been wet and dried for two or three days. All the briquettes were dried two days in the air, with occasional

1. New Jersey Geol. Survey, Vol. VI., p. 86.

2. F. F. Grout made the tensile strength tests on these clays, and gives the following account of his method and discussion of the subject of tensile strength.

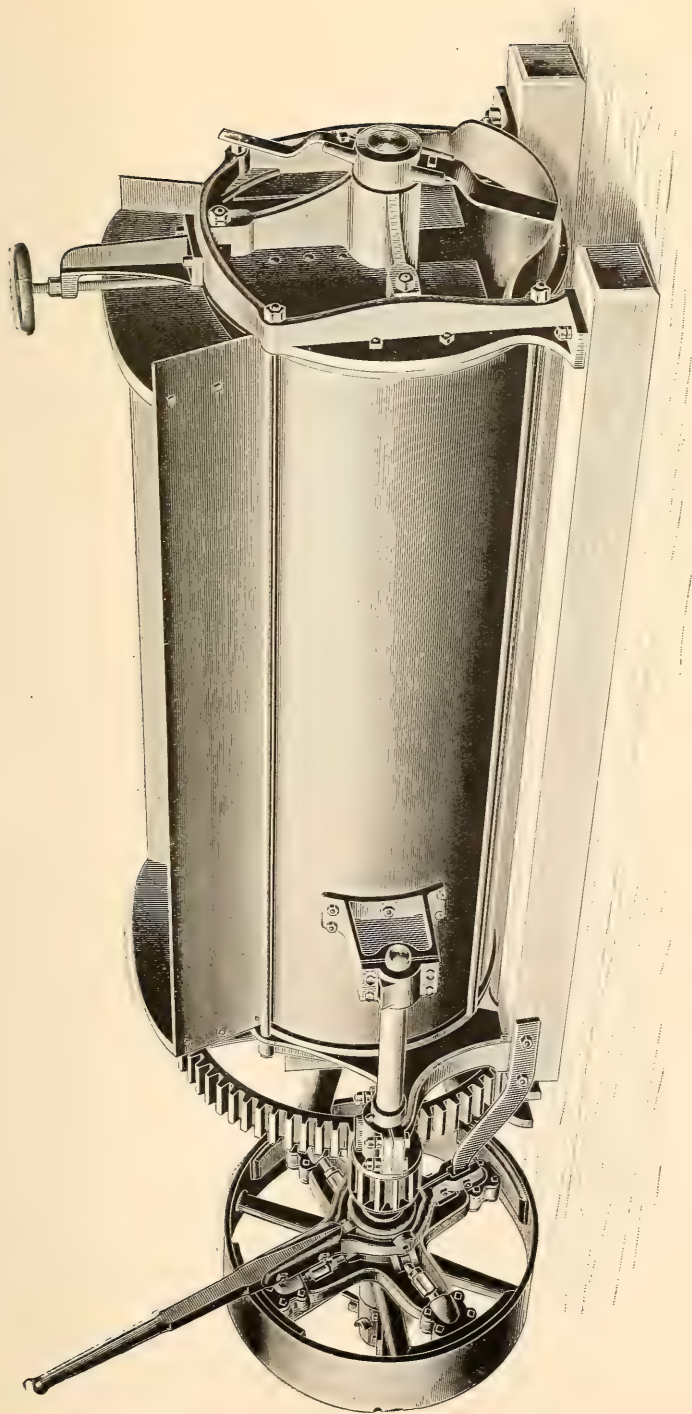


Plate IV.—American Clay Pug Mill.

turning, and finally at a temperature of 212° F. In order to determine the effects of rapid drying one briquette of each set was dried at about 200° F. as soon as molded.

When thoroughly dry, the briquettes are broken in a testing machine, in the present work in a Fairbanks type, which is convenient and compact in form. The briquette is placed in the clips of the machine and pulled apart by a certain number of pounds weight. The recorded weight is corrected for the shrinkage that occurred in the drying of the briquette reducing its cross section.

It appears to be more difficult to obtain a smooth break at the smallest section of a clay briquette than in a cement briquette, probably due to the irregular shrinkage of the drying clay. A large number of the briquettes break between the ends of the clips. But when briquettes of the same clay break, some at the center and others near the clips, no marked difference in results was found in our work, and the same conclusion was reached in the Iowa Survey work. All the results were used in computing averages, except where defects in structure were revealed. As a rule, the results should not vary over 20 per cent., but in some clays the variation is greater even when the utmost care and precaution are used.

The tensile strength of burned clay briquettes appears to stand in no definite relation to that of the unburned clay, and the results, according to the work of the Iowa Survey, are of doubtful value. No evidence was found to show that plasticity varied with the strength of dry clay briquettes. Dr. H. Ries¹ has well said that the importance of this property makes it worth while to investigate the causes of its high development in some clays. He has supplied some evidence that there might be a connection between texture and strength, and concludes that a mixture of good quantities of various sizes of grains is the strongest clay; because, as is easily shown, such a mixture allows a closer compacting of grains, and leaves less pore space. The cohesion of grains is stronger when acting over the shorter intervals so produced. But on looking over our more numerous results, we find too many exceptions to this rule, to think it a prominent factor, though it undoubtedly has its effect.

In the first place, cohesion, which produces the tensile strength, varies with the nature of the substance. Although Dr.

1. N. J. Geol. Survey, Vol. VI., p. 86.

Ries¹ thinks it is not sufficient to say that they cohere, we think it is sufficient, when we add that some substances cohere more strongly than others, and the cohesion depends, not on the chemical elements present, but rather on their condition, or the constitution of the substance, as shown in discussing plasticity.

But, however unnecessary it may be to search for a further explanation, we have noticed a constant relation between soluble salts and tensile strength. This becomes apparent when the average amounts of soluble salt for various tensile strengths are tabulated. The evidence is so clear that we have studied the determinations made by men in other states, and have tabulated three series, and the results are shown by the curves in Figure 5. Evi-

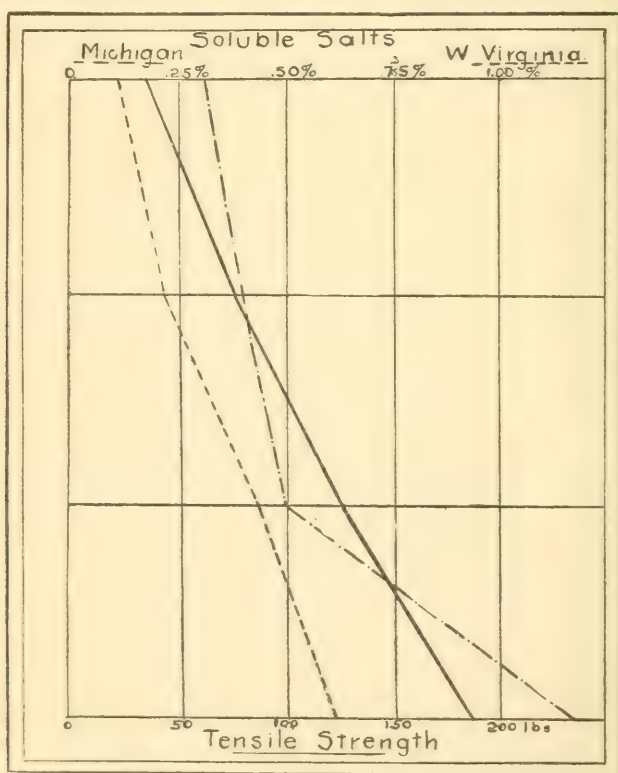


Figure 5.

dence is difficult to obtain, for the reason that few writers record

both soluble salt and tensile strength values for the clays they have tested. Experiments, to determine the effect of adding gypsum, alum, and silicic acid in small amounts to clays low in salts, gave varying results; but the average showed an increase in tensile strength.

Soluble Salts.	Tensile strength.			
	0-50 lbs.	50-100 lbs.	100-150 lbs.	150 lbs. up
West Virginia	.12	.20	.40	.58
New Jersey (H. Ries).....	.32	.43	.50	1.2
New York (H. Ries).....	.37	.54	.61	....

II. SLAKING.

Most clays, when placed in water, will disintegrate and break down into finer and finer particles, and this process is termed *slaking*.

Some clays will thus crumble to powder in a few minutes, others will break up into small masses, which will then slowly crumble. Certain clays will show very little change in the water for days, or even weeks, and then begin to crumble. There is a wide variation in time required for this operation in different clays. The time required for this change in masses of clay of the same size may be used for comparison of clays as to their slaking property.

This property developed in this artificial way is seen on a larger scale in the weathering of clays in the bank in a natural way, where the clay is disintegrated by atmospheric agents. The process is utilized in clays, and especially shales, which may slake slowly. The clay and shale are mined and allowed to remain in the air, exposed to the weathering forces. In the late fall the shales and clays are blasted out and allowed to remain through the dull winter season, and are thus ready for the opening of spring work. Hard flint clays which are only crushed with difficulty break up into small fragments, and these fragments have lost their resistance to crushing. The action may be hastened by throwing water or steam on the piles of clay or shale.

This slaking process aids in the ease of working the clays, requiring less power in grinding. It facilitates the removal of coarse impurities, and the removal of soluble injurious substances. It makes the clay finer in texture and so increases its plasticity. As has been stated, some non-plastic clays become plastic when weathered or ground. The time of slaking in our experiments is

the time required for a lump of dry clay, one-half inch in diameter, to fall into powder in an excess of water, so that practically no grains cohere. Shales often slake to fine particles and scales, which will gradually crumble still further for a long period of time.

12. FINENESS (Texture.)

Clay is composed of particles of kaolin and various mineral impurities. In a given clay these particles, while of different sizes, have a greater proportion of fine or coarse grains, and so form fine or coarse grained clays. The size of the grains and also the relative proportion of the grains of this size can be determined by microscopical examination.

Mechanical analyses are also made to determine these points. In this method, the clay is separated in revolving tubes at different rates of speed which throw the sediment, finer and finer grained, to the bottom as the speed is increased. The centrifugal method of mechanical analysis has been applied to such clays and shales as would slake in water to which was added a few drops of ammonia. The accuracy of the method and possible variations in procedure are discussed in Bulletin 24, of the Bureau of Soils, U. S. Department of Agriculture. The microscope was used to be certain that the particles separated were of the size stated.

The variation of the limiting sizes of particles for different groups is nearly as great as the number of authorities. Nearly all agree in calling all particles below .005 millimeters in diameter, *clay*. In the present work the clay has been separated into five groups: 1. *Fine clay*, 0.00 to .001 mm.; 2. *Coarse clay*, .001 to .005 mm.; 3. *Silt*, .005 to .02 mm.; *Fine sand*, .02 to .15 mm.; 5. *Coarse sand*, .15 to 3.0 or 5.0 mm.

In the case of shales, the two clay groups are combined, and coarse sand is divided into medium sand below 1.0 mm., and coarse sand above 1.0 mm. in diameter. The following analyses will illustrate these divisions:

Charleston Clay.		Clarksburg Shale.	
Fine clay (.00 to .001).....	14.9	{	14.8.....Clay (.00 to .005)
Coarse clay (.001 to .005)....	5.0		
Silt (.005 to .02).....	38.00		30.2.....Silt (.005 to .02).
Fine sand (.02 to .15).....	34.0		8.2.....Fine sand (.02 to .15)
			3.5.....Medium sand (.15 to 1.0)
Coarse sand (.15 to 3.0).....	7.0	{	41.6.....Coarse sand (1.0 to 4.0).

A more simple method is "to drop a lump of clay into a beaker of water where the clay slakes into a conical pile of particles that vary in size from one-fourth to one-twentieth of an inch in coarse clays; one-twentieth to one-fortieth of an inch in medium clays; one-fortieth to one-two-hundredth inch, in fine clays." Fineness of grain is one of the very important properties of clays because of its influence on plasticity, shrinkage, porosity, rate of drying, and fusibility.

The particles of different grades of fineness from some sixteen samples of clay were analyzed, with the results shown in the following table. Titanium is often described as present in very minute needles or grains, but these analyses show it is distributed in particles of different sizes from the smallest grains to a coarse sand. The silica percentage is higher in the coarser portions, where it probably is present in the form of sand or quartz. Alumina is higher in the finer material; but total figures are also higher, so that the finest particles are not the purest kaolin.

ANALYSES OF MATERIAL SEPARATED BY MECHANICAL METHOD.

Sizes.	00 to .001	.001 to .005	.005 to .02	.02 to .15	.15 up.
SiO ₂	44.08	54.54	70.30	81.16	73.63
Al ₂ O ₃	28.16	23.00	16.04	9.76	13.01
Fe ₂ O ₃	7.94	5.91	3.21	2.13	4.71
FeO	.99	.99	.63	.40	.18
MgO	1.36	1.02	.80	.39	.48
CaO	.76	.82	.72	.31	.47
Na ₂ O	.00	.29	.45	.56	.00
K ₂ O	3.05	3.31	2.14	1.78	.93
H ₂ O	2.80	1.10	.56	.35	.87
Ignition	10.86	7.79	4.33	2.59	4.40
TiO ₂	.84	1.12	1.08	.78	.60

Fineness of grain increases the plasticity, as has been shown under that head. So marked is its influence in this direction that it was at one time looked upon as the cause of plasticity. The finer the grain of a clay the greater the shrinkage in most cases, though there are exceptions to this rule. A fine grained clay will absorb more water than a coarse grained one, the water being held mainly in the form of surface films around the more numerous clay particles.

Fineness of grain also determines to some extent the porosity of a clay. In coarse grained clays the pores are larger than in the fine grained types; for this reason, the texture has an im-

portant bearing on the rate of drying, as the water can be removed more readily from the coarse grained clay, and with less danger, as a rule, of cracking the ware.

When clays are subjected to high temperatures the heat passes through from particle to particle. If these particles are large the transfer of heat will be slower than if fine grained. Further, the small size of the particles would permit them to fuse more rapidly than if larger. In the coarse grained clays, the pores are apt to be larger, and so separate the particles, thus lowering the rate of heat transmission, and the fluxing action of one component on another would be more effective the nearer the particles are together. For these reasons the finer the texture of the clay, other conditions remaining uniform, the more fusible it will be.

13. POROSITY.

Clays not only vary in size and shape of grain, but also in the closeness of grain. In a clay mechanical analysis shows that the grains are of varying size from coarse sand to fine silt or clay; microscopical examination shows that the grains not only vary in size but also in shape.

Such an aggregate of particles of different sizes and shapes brought together would have many open spaces or pores, and the ratio of the volume of these pores to the total volume of the clay would represent the *porosity* of the clay.

The porosity of the clay could be tested by the amount of liquid which would be absorbed, provided the liquid used did not slake the clay. Rapidity of absorption is sometimes incorrectly considered a measure of porosity. Coarse grained clays will take up water more rapidly than fine grained, yet in time the amount absorbed might be the same. The river clays are usually open, loose textured clays, with large pore spaces, while the flint clays are more compact, with smaller pore spaces, when removed from the bank, though the total amount of porosity might be greater than in the river clay. Tests for porosity should be made on the clay which has been ground and tempered, rather than on the clay direct from the bank, as there may be a marked difference in results in the two cases, and tests on the former clay would be more practical.

In burned ware the amount of absorption of water may have an important bearing on the value for certain uses. In paving brick not over $3\frac{1}{2}$ per cent of water should be absorbed. All burned ware, unless thoroughly vitrified, will be porous, and so is capable of absorbing moisture. Absorption is a measure of weight of water filling the pore spaces, while the true measurement of porosity would be one of volume. As it is easier in manipulation to measure the weight of water absorbed than the volume filled, the absorption test is the one usually applied.

If the ware be exposed to changes of weather, this absorbed water may be detrimental. In cold weather, the water in the pores freezing would exert a pressure against the clay grains, tending to break them apart. If the pores are large, this pressure may find relief through the surface pores, but if minute in size, the pressure comes against the particles, breaking them apart. In the porous flower pots and soft burned brick, the pore space would be large and absorption of water thereby high. In the vitrified brick, the pore space would be very small and absorption low.

Beyer¹ gives the following method for measuring porosity: The clay is worked with water to its maximum plasticity and a pat made about one-half inch thick. From this pat strips are cut three by one and one-half inches, dried, and after weighing are placed in kerosene oil of known gravity, until saturated, then weighed. If v represents the volume of the dry test pieces, g the difference in weight between the dry and saturated piece (weight in grams of oil absorbed), s the specific gravity of the oil, the percentage of porosity would be represented by the formula,

$$PERCENTAGE\ POROSITY = \frac{g}{s \cdot v} \cdot 100$$

In testing the burned ware distilled water could be used (specific gravity equalling 1) and formula would be:

$$PERCENTAGE\ POROSITY = \frac{g}{v} \cdot 100.$$

1. Iowa Geol. Survey, Vol. XIV., p. 112.

14. SPECIFIC GRAVITY.

The density of a body is measured by its specific gravity, which represents the weight of a substance compared with an equal volume of water. It is a useful property in comparing relative weights of bodies. The volume of a solid may be determined by weighing it in the air and then in water, the difference in weights being the weight of the volume of water displaced, which volume is equal to that of the solid. The weight of the substance divided by its volume is the *specific gravity* of the substance.

In clays the specific gravity of the mass will vary with consolidation of the clay. Clays of the same mineralogical composition would thus vary in specific gravity, and the specific gravity of the clay as taken from the bank would be different from that molded into ware, since the grinding, tempering and molding would consolidate the clay and so change the results.

Specific gravity of clays could therefore be measured in two ways, by determining this factor for the lump of clay including the mineral particles and pore space, which determination would be of little practical value in direct applications or in comparison with other clays; this method would give the *apparent specific gravity*. Or, the specific gravity of the mineral components minus the pore space could be determined, which would give the *true specific gravity* valuable for comparison.

If the porosity is known¹ then 100 per cent. minus the percentage of porosity would give the percentage of volume occupied by clay particles, which multiplied by the entire volume of the clay would give the space in cubic centimeters occupied by the mineral particles. The weight of the clay sample divided by this calculated volume would give the true specific gravity according to the formula.

$$\frac{W}{V (100 \text{ Per cent.} - P)} = \text{Spec. Gravity.}$$

where **W** is the weight of the sample, **V** is the volume of the sample, and **P** is the percentage of porosity.

The true specific gravity as thus determined would be constant for the given clay when taken from the bank, or when treated according to the various methods of manufacture. It would

1. Iowa Geol. Survey, Vol. XIV., p. 115.

furnish an accurate means of comparison of clays according to their density.

The mineral kaolin which forms the base of clays has a specific gravity of 2.6, that is, a given bulk of this mineral weighs 2.6 times as much as an equal bulk of water. Iron impurities would have a higher gravity and most of the other impurities would have a lower gravity, so that the mineral mixtures in clay would usually give the clay a specific gravity below 2.6. The range of specific gravity in clays in different sections is shown in the following table:

Georgia clays ¹ (Apparent Spec. Gravity).....	1 to 2.5
Missouri clays ² (Apparent Spec. Gravity).....	1.69 to 2.56
New Jersey clays ³ (Apparent Spec. Gravity).....	1.52 to 2.32
New Jersey clays ⁴ (True Spec. Gravity).....	2.34 to 2.84
Iowa clays ⁵ (True Spec. Gravity).....	2.32 to 2.64
North Carolina clays ⁶ (True Spec. Gravity).....	2.24 to 2.68

In the above determinations the apparent specific gravity, which includes pore space as well as mineral particles, shows lower results.

The porosity and specific gravity were determined for but few of the West Virginia clays. The picnometer was used and the results check by the determination of porosity and apparent specific gravity as described above from the Iowa survey report:

Clay.	Apparent Sp. Gr.	Porosity.	—Real Specific Gravity.— Calculated. By Picnometer.	
Pt. Pleasant River Clay....	1.75	30.2%	2.51	....
Barboursville Clay	1.68	29.1%	2.37	....
Clarksburg Clay	1.92	23.8%	2.52	....
Morgantown Shale	1.86	25.5%	2.49	....
Morgantown Shale	1.88	26.1%	2.53	....
Bridgeport Pottery Clay ..	1.76	25.1%	2.35	....
Thornton Plastic Clay	1.84	23.6%	2.41	....
Thornton Flint Clay	1.94	25.8%	2.61	....
Hammond Flint Clay	1.71	26.5%	2.34	2.57
Charles Town River Clay..	1.88	29.4%	2.66	2.61
Weston River Clay .....	....	....	....	2.68
Parkersburg Pottery Clay..	....	....	....	2.58

1. Geol. Survey of Georgia, Bull. No. 6-A, p. 20.

2. Missouri Geol. Survey, Vol. XI., p. 90.

3. Geol. Survey of New Jersey, Clays, 1878, p. 284.

4. Geol. Survey of New Jersey, Vol. VI., p. 114.

5. Iowa Geol. Survey, Vol. XIV., p. 116.

6. North Carolina Geol. Survey, Bull. 13, p. 146.

CHAPTER IV.

CLASSIFICATION AND USES OF CLAYS.

With all their variable characters, chemical and physical, clays may be arranged in a limited number of groups for convenience in examination and description. As the convenience of one investigator is not the same as that of another, the published schemes of classification of clays rarely agree. Clays have thus been classified according to their origin, according to their chemical or physical properties, or according to their uses.

LADD'S CLASSIFICATION.

A classification according to origin and mode of occurrence was given by Ladd¹ in his work on the clays of Georgia in the following outline:

INDIGENOUS.

- A. Kaolins.
 - (a) Superficial sheets.
 - (b) Pockets.
 - (c) Veins.

FOREIGN OR TRANSPORTED.

- A. Sedimentary.
 - (a) Marine.
 - 1. Pelagic.
 - 2. Littoral.
 - (b) Lacustrine.
 - (c) Stream.
 - 1. Flood-plain.
 - 2. Delta.
- B. Meta-sedimentary.
- C. Residual.
- D. Unassorted.

In this classification indigenous clays are those which have been formed by the decay of feldspar or other aluminous silicates in place, and remain at the place where first formed, and include the purest clays or kaolins. The second group of foreign or transported clays includes those clays removed by aqueous or aerial

1. Geol. Survey of Georgia, Bull. 6-A., p. 10.

forces to points more or less distant from the place of origin. In this division the most important group is the sedimentary, including all clays deposited as sediments through the agency of water.

Those clays deposited in salt water are called marine and are subdivided into *Pelagic*, deposited in the deeper portions of the sea, and *Littoral*, deposited near the shores. The *Lacustrine* clays are those deposited in fresh water lakes while the *stream* clays have been deposited along the borders of streams in the *flood plains*, or at the mouth in *deltas*.

Meta-sedimentary clays are chemical products formed by the decomposition of other transported sediments, such as volcanic tufas, pumice, etc. Residual clays in this classification are those which were transported in past time but included in lime formations, the latter dissolving away would leave as a residuary mass, unweathered clay particles. Unsorted clays have been transported by glacial action, and are commonly called boulder clays. They are without definite bedding planes.

BUCKLEY'S CLASSIFICATION.

The classification given above was modified by Buckley¹ in his report on the clays of Wisconsin by basing the primary divisions on position, and the secondary ones on origin as follows:

- I. Residual *derived from*—
 - A. *Granitic or Gneissoid Rocks*,
 - B. *Basic igneous rocks*,
 - C. *Limestone or dolomite*.
 - D. *Slate or shale*.
 - E. *Sandstone*.
- II. Transported by—
 - A. *Gravity assisted by water*.
Deposits near the heads and along the slopes of ravines.
 - B. *Ice*.
Deposits resulting mainly from the melting of the ice of the Glacial Epoch.
 - C. *Water*.
 - 1. Marine.
 - 2. Lacustrine.
 - 3. Stream.
 - D. *Wind*.
Loess.

1. Wisconsin Geol. Survey, Bull. VII., Part I, p. 14.

BEYER'S CLASSIFICATION.

A grouping of clays primarily on origin and secondarily on the physical and chemical properties is found in the following classification by Beyer¹ used in his work on the clays of Iowa:

PRIMARY OR RESIDUAL CLAYS.

Entirely decomposed feldspathic rock.

Kaolin or china clay.

Partially decomposed feldspathic rock.

English Cornwall stone,

Porzellan Erde of the Germans.

SECONDARY OR TRANSPORTED CLAYS.

Deposited in still water,

Fire clays,

Highly refractory,

Flint fire clay,

Plastic fire clay.

Moderately refractory,

No. 2 fire clay,

Stoneware clay.

Sewer-pipe clay.

Shales,

Slaty shales,

Bituminous shales,

Clay shales.

Deposited from running water.

Alluvium,

Sandy clays,

Loam.

Deposited by glacial action.

Leached—Whitish or red boulder clay.

Unleached—Blue boulder clay.

Deposited by winds.

Loess.

ORTON'S CLASSIFICATION.

The classification according to uses is shown in the following table, given by Professor Edward Orton, Sr.,² in the Ohio survey reports:

HIGH GRADE CLAYS.

(50 per cent. or more kaolin) with silica.

- | | |
|---|-------------------------|
| { | 1. Kaolin. |
| | 2. China clay. |
| | 3. Porcelain clay. |
| | 4. Fire clay (hard). |
| | 5. Fire clay (plastic). |
| | 6. Potters' clay. |

1. Iowa Geol. Survey, Vol. XIV., p. 40.

2. Geol. Survey of Ohio, Vol. VII., p. 52.

LOW GRADE CLAYS.

(10 to 70 per cent. kaolin, with notable per cent. fluxing elements).

- | | |
|---|---|
| { | 1. Argillaceous shale — paving block. |
| | 2. Ferruginous shale — pressed brick. |
| | 3. Silicious clays — Sewer pipe and paving block. |
| | 4. Tile clays. |
| | 5. Brick clays. |
| | 6. Calcareous shales—brick. |

WHEELER'S CLASSIFICATION.

Along the same line is the classification given by Wheeler¹ in the work on clays of Missouri :

1. WHITE WARE CLAYS.

Kaolin.
China clay.
Ball clay.

2. REFRACTORY CLAYS.

Plastic fire clay.
Flint clay.
Refractory shale.

3. POTTERY CLAYS.**4. VITRIFYING CLAYS.**

Paving brick clay and shale.
Sewer pipe clay and shale.
Roofing tile clay and shale.

5. BRICK CLAYS.

Common brick clay and shale.
Terra cotta clay and shale.
Drain tile clay and shale.

6. GUMBO CLAYS—Burnt ballast clay.**7. SLIP CLAYS.**

A classification, based on origin and subdivided according to the uses of clay, as determined by their chemical and physical properties, would be especially valuable in practical work, but it is difficult to make in this way a perfectly satisfactory classification because of the different chemical and physical characters of clays used for similar purposes, and their different modes of origin.

The following classification, while not entirely satisfactory, will perhaps serve its purpose of grouping the clays in a convenient form for description :

1. Missouri Geol. Survey, Vol. XI., p. 25.

I. RESIDUAL CLAYS.

1. Kaolin.
2. China or porcelain clay.

II. TRANSPORTED CLAYS.

- A. REFRACTORY (fluxing impurities low).
 3. Flint fire clay.
 4. Plastic fire clay.
- B. SEMI-REFRACTORY (fluxing impurities medium).
 5. Paving brick clay and shale.
 6. Sewer-pipe clay and shale.
 7. Roofing tile clay and shale.
 8. Stoneware clay.
- C. NON-REFRACTORY (fluxing impurities high).
 9. Pottery clays,
 - (a) Ball clay,
 - (b) Flower pot clay.
 10. Brick and tile clay and shale:
 - (a) Ornamental brick clay and shale.
 - (b) Terra cotta clay and shale.
 - (c) Ornamental tile clay and shale.
 - (d) Common brick and tile clay and shale.
 11. Gumbo ballast clay.
 12. Slip clay.

While, for example, paving brick and sewer pipe clays will also make common brick, the clays to be included under brick and tile clays would not usually make paving brick or sewer pipe. As has been stated, this classification, or any other one based on uses, will have overlapping divisions and so cannot be regarded as a scientific arrangement. On the other hand, a scientific classification according to origin without any reference to the uses of the clay cannot be satisfactory to the clay worker.

GENERAL DESCRIPTION OF CLAYS.

I. RESIDUAL CLAYS.

The residual clays are those which have been first formed in the place where they are now found. They have resulted from the decay of the components of the original rock and therefore contain a less amount of foreign impurities than clays transported from their point of origin to more or less distant points. The wash from adjacent hillsides would not be mixed through and through the residual clays. They would include as impurities only the other components of the parent rock.

The term residual in this classification is restricted to the first formation of the clay or kaolin substance. In another sense the decay of limestone, sandstone, and possibly compact shale, would

form clays which would be in place and therefore residual; but it must be remembered that the clay substance locked up in these sedimentary rocks has been transported at some past time, and would thereby be excluded from the division of residual clays in this classification, for they were not *first* formed in the place where they are now found.

On account of their purity, the residual clays are used for products of the highest grade, for fine china or porcelain ware. The first group, the kaolins, include the purest clays known, those which approach most closely to the theoretical composition of the mineral kaolin. They are usually formed, when in commercial quantity, from feldspar. There is no question that feldspar alters into kaolin and that the large deposits of kaolin are thus formed. Just what causes the change is an unsettled question, for while in nature this alteration is common and apparently simple, it is almost impossible to reproduce the change in the laboratory by artificial means.

The kaolin clays are white in color when pure, of light, soft texture, non-plastic, and usually mixed with mica flakes, quartz and feldspar grains. Under the microscope the kaolin shows bunched and scattered scales. They occur in masses and veins of varying depth and extent through the crystalline rock areas. Deposits are found at various places in the Appalachian mountains from New York into Alabama. They also occur in other crystalline rock areas of the country.

When the quartz and feldspar impurities occur in coarse crystals, they may be removed by washing. The troublesome impurity is iron, for if this is present above two per cent. it will tinge the burned ware, injuring the value of the clay for high grade china. The kaolin is washed by throwing it into circular vats where it is stirred and thoroughly mixed with water by revolving arms carrying knives. From these vats the mixture passes to a shaking screen which holds the coarser particles and permits the fine clay and water to pass through to an agitator or to a settling tank. The mass of fine kaolin and water is pumped into filter presses where the water is forced out and the sheets of kaolin are removed and thoroughly dried. From a ton of crude kaolin about two-fifths or one-fourth of a ton of washed kaolin is obtained¹.

1. North Carolina Geol. Survey, Bull. 13, p. 58.

The kaolin clays, being non-plastic and almost infusible, could not be used alone in manufacture. In order to make chinaware from kaolin clays, they must be mixed with ball clay to add plasticity, with ground quartz to counteract the resulting shrinkage, and to hold these materials together a fusible component must be added, like feldspar. In the manufacture of certain porcelains the following mixtures are used:¹

	Japanese porcelain. Per cent.	Belgian white earthen ware. Per cent.
Clay	49.44	58.56
Quartz	45.36	30.36
Feldspar	5.20	11.08
	100.00	100.00

In the West Virginia potteries the kaolin clays used are shipped from England, from near Webster, North Carolina, from Georgia, and New Jersey. The most famous china clays in the world are those in France near Limoges and Sevres, and in Germany near Dresden. These are very pure clays and make a grade of china which is standard the world over. Their composition and that of the North Carolina kaolin are shown in the following table from Ries:

	Webster, N. C. ²	Limoges ³	Dresden ⁴
Silica	45.70	58.89	50.15
Alumina	40.61	27.52	32.00
Ferric oxide	1.32	0.86	0.64
Lime	0.45	1.52	0.33
Magnesia	0.09	0.41	Trace.
Alkalies	2.82	4.29	0.47
Water	8.98	7.19	10.81
	100.04	99.68	100.40

So far as known, there are no deposits of any extent in this State. As has been indicated, kaolin clays result from the disintegration of crystalline rocks containing feldspar or other silicate minerals. With the possible exception of a small area in Pendleton county, no rocks of this type occur within the State. Small deposits of bleached clays are sometimes found which may resemble kaolin in color, but when analyzed are found to be impure

1. U. S. Geol. Survey, 19th Annual, Part VI., cont'd., p. 380.

2. Geol. Survey of New Jersey, Vol. VI., p. 297.

3. U. S. Geol. Survey, 19th Annual, Part VI., cont'd., p. 402.

4. U. S. Geol. Survey, 19th Annual, Part VI., cont'd., p. 416.

clays. These deposits are found from time to time at different places in this State and are reported as kaolin clay.

In the use of kaolin clay with quartz, feldspar, and ball clay to make the fine grades of china or porcelain, the proportions of the substances used are secrets of the manager and they are weighed on scales whose weight pans are hidden in a locked compartment. According to the purity of the product three grades are made, known as C C (cream colored), white granite ware, and china. In the first, the ware is tinged in color, which may be concealed in part by the glaze.

White granite ware is white in color and strong in body so as to withstand hard usage, partially vitrified or semi-vitrified and not translucent. In the American trade there is a tendency to call this ware porcelain in contrast with the finer grades of china, though this is rather an arbitrary use of the term, and not adopted in scientific descriptions where porcelain is used as a synonym of china. In china ware, the product is vitrified and is more or less translucent, permitting the light to be transmitted through it. This fusion is at rather low temperatures and the purest materials are used, which are mixed and fired with the greatest care.

In some localities kaolin clays are found with a small percentage of impurities and the clays are somewhat plastic. They can be burned without further mixture into ware. While such clays would grade into kaolins, Wheeler has suggested they may be called *china clays* in distinction from kaolin clays.

II. TRANSPORTED CLAYS.

The larger group of clays includes those which have been removed from their first place of origin. It includes a great variety of clays which are more widely distributed than the preceding group, and they are more valuable clays from an economic standpoint. In this group are found the clays used for structural materials, and for refractory purposes. This is the important clay group in West Virginia. The clays are impure through the admixture of foreign elements.

In the classification herein adopted the transported clays are divided into three groups according to their refractory or fire-proof characters, which depend on the amount of fluxing impurities present. On account of the gradation between the clays

in these different groups, it would be difficult to give the percentages of fluxing impurities in them.

A. REFRACTORY CLAYS.

Refractory clays have the property of withstanding the effects of high temperature, and are therefore valuable in work where such temperatures are used. They are used for fire brick for furnaces, kilns, fire places, etc., for gas retorts, glass pots. In the latter, the clays must be of highest grade to stand the high temperature and corrosive effects of the molten glass.

The first group, flint clays, are very hard, compact, flint-like rocks, breaking with a conchoidal or shelly fracture. Many of them on exposure to the air slake and crumble. They vary in purity from those nearly as pure as kaolin to very impure forms. They are sometimes streaked and mottled with dark shades of color due to organic matter, and again, are very light in color, being almost white. As a rule, they are non-plastic and do not become plastic when weathered or ground. In order to use them in the manufacture of brick, a plastic clay must be added.

In many places the plastic clay is found with the flint clay either above or below. There are some excellent deposits of flint fire clay in this State and the deposits are used for the manufacture of fire brick, and also mixed with a large proportion of the plastic fire clay and made into an excellent quality of street paving brick. The chemical composition of the flint clays is shown in the following analyses:

	Mineral Point, Ohio. ¹	Mt. Savage, Md. ²	Piedmont, W. Va. ³
Silica	52.52	56.14	61.44
Alumina	31.84	33.295	26.18
Water	11.68	9.60	9.84
Iron	0.67	0.59	0.66
Lime	0.50	0.17	0.12
Magnesia	0.19	0.115	0.04
Alkalies	0.59	.....	0.02
Titanic acid.....	1.68	.....	1.39

The *plastic fire clay* is sometimes found with the flint clay, and one may even grade into the other. It usually lacks the compact texture and is more open, breaking with irregular fracture.

1. Ohio Geol. Survey, Vol. VII., p. 220.

2. Maryland Geol. Survey, Vol. IV., p. 451.

3. F. F. Grout.

It weathers into a soft sticky clay and is often used for paving and other kinds of brick.

Under every normal coal seam there is a bed of clay called fire clay, though it does not always deserve this name. It is usually a plastic clay and some of our best clays in this State are found in this position, and some are plastic fire clays. Plastic fire clays differ from other plastic clays in the lower percentage of fluxing impurities, iron, lime, magnesia, and the alkalies. Their composition is given in the following table:

	Bolivar fire clay, Ohio. ¹	Almerade, Germany. ¹	Piedmont, West Va.
Silica	60.56	72.33	51.34
Alumina	24.97	19.06	29.75
Water	8.90	5.52	0.98
Iron	1.66	0.71	3.72
Lime	0.63	0.28	0.31
Magnesia	0.40	0.18	0.49
Alkalies	0.28	0.59	1.63
Titanic acid.....	1.30	....	2.13

In mixing the flint clays and plastic fire clays for fire brick, enough plastic clay is used to make a good bond so the brick may be handled, for at high temperatures the flint clay particles will fuse and give strength to the brick. The conditions which produce a good fire brick mixture, according to Orton², are: 1. Enough flint clay to give the fire resisting power; 2. Enough plastic clay to give physical strength for use until the bricks are in position and placed under high temperature, when the flint clay, fuses and forms the true bond; 3. The bricks must be loose and open grained in texture so as to admit of rapid absorption of heat; 4. Since the flint clay has a high shrinkage, it is necessary that the plastic bond clay should be of very low shrinkage and further that part of the flint clay should be calcined before use, so as to remove the shrinkage, and thus permit the union of the clay particles to remain unbroken when burned. The mixture used for these conditions would be about 45 per cent. calcined flint clay, 45 per cent. raw flint clay and 10 per cent of plastic bond clay. If the brick are to be used at lower temperatures, the proportion of flint and plastic fire clay is about one-half of each.

1. Ohio Geol. Survey, Vol. VII., p. 222.

2. Ibid, p. 223.

B. SEMI-REFRACTORY CLAYS.

The clays in this group are not used for fire resistance, but for ware which requires a firm, tough body, with a low water absorption. They are clays which vitrify, which means that under sufficient heat the clay partially melts and the particles are thus brought closer together, with a more or less complete removal of the pore space. A good fire brick is porous, while the vitrified wares, in contrast, are non-porous, or better, the pore space is reduced to a minimum.

The clays for these uses must be fusible, but in order to be valuable must also have the points of incipient fusion and viscosity removed from each other by a sufficient number of degrees to enable the clay to be partially fused but not melt the whole product. This is important for two reasons: First, it is difficult to determine in a kiln just when vitrification has gone far enough for a completed product, and to be perfectly safe it is convenient for the operator to keep the ware at this temperature for a time and yet not melt down the contents of the kiln; second, the ware in reaching the point of vitrification must have sufficient strength to hold itself in shape even under the pressure of overlying layers. If the ware was completely melted it would lose the required form and size. In the manufacture of vitrified ware the clay must also be plastic enough to be moulded, and if made in the form of brick or tile which are pressed through dies, they must not be over plastic so as to injure the structure of these products.

The iron percentage would also be important in determining the color of the ware. As it is rare to find a clay possessing all these conditions, it is often necessary to mix clays of different characters in determined proportions. Such a mixture must have the proportions carefully determined and the materials must be ground into an intimate and uniform mixture.

In the manufacture of paving brick, clays and shales are used. It was formerly believed that shales were not adapted to this work, but now many of the standard grades of paving brick are made entirely from shale, and many manufacturers claim shale makes a better product. A clay or a shale which accords with the above conditions would be adapted to this work. The mere fact of being in form of clay or shale would make little difference. In this State, both are used together and separately. In a

number of the plants it is found that better results are obtained from using a mixture of different shales, or shale and clay. Some of the plants by experimenting on such mixtures have found that while a given shale or clay makes a good paving brick, the mixture gives a better product.

In these days of strong competition it becomes necessary to improve the grade of paving brick as much as possible. Inferior grades of paving brick have found sale, and find a limited sale at the present time, where the price is lower than better grades, but this condition is becoming less and less true. Nearly all city specifications are now rigid, and when enforced will only admit the best grades of brick. It therefore becomes a matter of the highest importance to the paving brick companies to know the characters of their clays and how to use them to the best advantage.

Fusion, shrinkage, absorption, and other tests of clays in this day lose their theoretical character, and become very practical and essential. The following analyses show the composition of some paving brick clays and shales:

	Darlington, Ohio. ¹	Charleston, West Va.	N. Cumberland, West Va.	Avg. From 50 Sources. ²
Silica	57.45	51.07	57.89	56.0
Alumina	21.06	25.78	21.59	22.5
Water	5.90	1.41	7.45	7.0
Iron	7.54	6.83	6.88	6.7
Lime	0.29	0.57	0.61	1.2
Magnesia	1.22	1.26	1.55	1.4
Alkalies	3.66	3.44	3.57	3.7

In the Ohio paving brick clays and shales, the temperature of vitrification ranges from 1712° to 1920°, F., with an average of 1860°. In Missouri the range was from 1600° to 1900°, F. The interval between the temperature of incipient fusion and viscosity in the best paving brick clays and shales is from 300° to 400° F.

In the manufacture of sewer pipe, the clays must have about the same qualities as those used for paving brick. The clay must be plastic and burn to a dense, smooth body. The shrinkage must be low in order to produce a uniform product, and avoid cracking or warping. While the color is not important in determining the useful qualities of the pipe, it has an important influ-

1. Ohio Geol. Survey, Vol. VII., p. 133.

2. Missouri Geol. Survey, Vol. XI., p. 456.

ence on the sale, as the trade usually demands a dark, uniform colored ware. There must, therefore, be the requisite amount of iron to produce this result. Sewer pipe is usually salt glazed, which requires enough free silica to decompose the salt. When fire clays are used for sewer pipe, the product is light colored, which may be overcome by adding an iron clay.

In the manufacture of roofing tile, the clay must vitrify and form a dense and tough body. It must give a good color and have a low air and fire shrinkage, as the thin plates are apt to warp and destroy the shape of the tile. The finished product must be light in weight, true in shape and possess strength, so that it can be handled and shipped without breaking.

In California and other sections where the injurious effects of freezing and thawing are absent, roofing tile are burned at lower temperature and not vitrified. In such regions less care is required in manufacture, and a greater variety of clays may be used.

In the two roofing tile plants in West Virginia, two different shales are mixed and ground. A red shale is mixed with a yellow sandy shale, which have the following composition :

	Red shale, Huntington.	Yellow shale, Huntington.	Buff shale, Parkersburg.
Silica	52.31	58.91	68.42
Alumina	22.31	20.00	16.38
Water	1.58	1.79	0.00
Iron	10.00	6.93	4.94
Lime	0.62	0.52	0.94
Magnesia	1.92	1.75	1.80
Alkalies	3.41	2.80	1.56
Titanic acid.....	0.84	0.71	0.88

Stoneware is a partially vitrified product which is burned and glazed before removal from the kiln. On account of the demand for this ware in household use, it is made in all sections of the country. With the number of clays adapted to this work in West Virginia, it is strange that there are only two plants in operation, and a large portion of the stoneware is shipped in from other states.

The properties required in a stoneware clay, according to Wheeler¹, are: 1. The clay should be very plastic; 2. It should be

1. Missouri Geol. Survey, Vol. XI., p. 299.

free from coarse sand or other foreign matter; 3. As free from iron as possible; 4. Capable of burning to a close, incipiently vitrified body at a temperature less than 2200° F.; 5. The clay should have a range of at least 200° between the point of incipient and complete vitrification; 6. It should be capable of drying and burning at moderate speed without the employment of grog; 7. It should form a tough and strong body when burned; 8. It should be free from carbonates, sulphates, or other salts that are liable to cause blisters in burning.

The clay must be very plastic in order that it may be easily molded and turned into the various patterns. If coarse materials occur in the clay, they will appear as defects in the finished ware. It thus becomes necessary in the use of most clays to wash them before molding. This removes the coarse impurities and also renders the clay more uniform in character. The presence of iron will give a dark colored ware, while the trade usually demands the light color. If the iron be unevenly distributed the ware will be spotted. These troubles are overcome to some extent in washing the clays.

On account of the uses of stoneware to hold liquids, it is necessary that the ware be partially vitrified so as to form a non-porous, compact body, and the required temperature should be low, so that less fuel would be required and lower the cost.

If the ware be completely vitrified, it has a glassy texture and is brittle. In order to safely reach the point of incipient fusion and not pass to that of complete vitrification, it is essential that there should be a range of a few hundred degrees between these points.

For economy and safety in handling the ware, the clay should have the character of more or less rapidly drying and burning. It should be possible to dry the ware as it comes from the wheel or mold in a short time without cracking or checking. By adding burned clay or grog, this result could be accomplished, but the thinness of the ware and strength required would prevent its use. The final product must be tough and strong to stand the hard usage given such products.

The presence of carbonates, sulphates, etc., in the clay is injurious, because in burning these will form gases which in their escape will form blisters on the ware, rendering it unsalable. The

following analyses shows the chemical composition of stoneware clays:

	Roseville, Ohio. ¹	Akron, Ohio. ¹	Parkersburg, West. Va.	Bridgeport, West Va.
Silica (combined)...	25.60	25.48	21.90	36.09
Silica (free).....	43.73	42.65	51.43	24.25
Alumina	19.08	20.80	14.98	20.55
Water	5.57	5.72	5.78	8.77
Iron	1.26	1.20	1.99	4.02
Lime	0.60	0.42	0.43	0.38
Magnesia	0.63	0.37	0.45	1.12
Alkalies	2.16	2.55	2.22	3.62
Titanic acid.....	0.29	....	0.81	0.92

C. NON-REFRACTORY CLAYS.

In this group are included the common pottery clays, and the clays valuable for structural materials. Many of them are very impure clays, with low percentage of kaolin.

Pottery Clays.

The highest grade clay in this division is the ball clay, which is used for a bond with the pure china clays. This clay represents a kaolin clay removed from its place of origin, and it is a very plastic clay in contrast with the non-plastic kaolin clays. The ball clays used in the potteries of this country come from Florida, New Jersey, Missouri and from England. Their composition is as follows:

	Edgar, ² Florida.	South Amboy, ² New Jersey.	Devonshire, ³ England.
Silica	46.11	44.89	52.06
Alumina	39.55	37.27	29.38
Water	13.78	14.47	10.27
Iron	0.35	0.97	2.37
Lime .....	....	0.41	0.43
Magnesia	0.13	0.19	0.02
Alkalies .....	....	1.44	2.29
Titanium	1.20	....	....

The deposit at Edgar, Florida,⁴ is 30 feet thick, and consists of 75 per cent. of quartz pebbles and 25 per cent. of clay. The quartz is washed out and the clay shipped to the potteries of the North. In the china potteries of West Virginia the Florida and English clays are used for the bond with the kaolin clays.

1. Ohio Geol. Survey, Vol. VII., p. 94.

2. New Jersey Geol. Survey, Vol. VI., p. 296.

3. U. S. Geol. Survey, 19th Annual, Part VI., cont'd. p. 405.

4. New York State Museum, Bull. 35, p. 614.

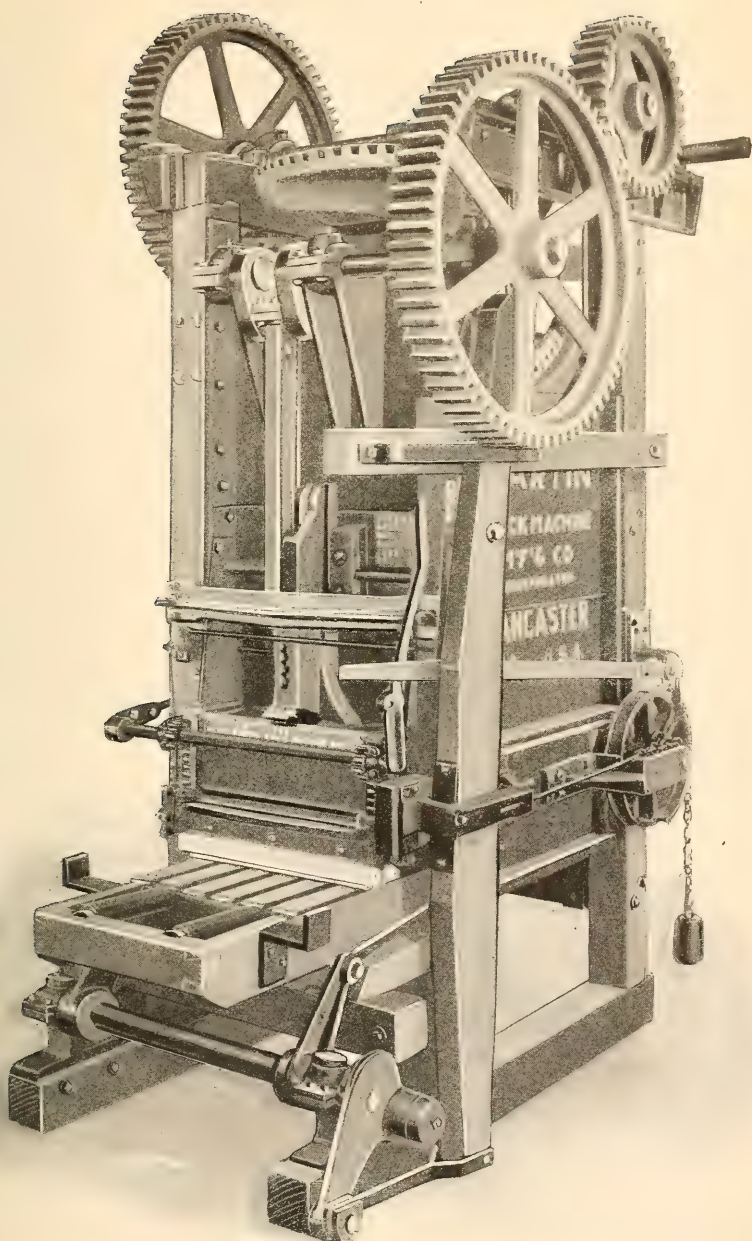


Plate V.—Martin Vertical Soft Mud Brick Machine.

In the manufacture of flower pots, low grade clays are used. They are burned at low temperature, and form a porous body. The clay must be plastic and give a good color. Many of the common brick and tile clays are adapted to this purpose.

Brick and Tile Clays.

The building brick and tile clays are usually impure, more or less sandy clays. The kaolin base is low in amount. The iron present determines the color, and the percentage in this State is usually sufficient to give a red color when burned.

As a rule they are not adapted to production of a vitrified body, fusing rapidly at elevated temperatures and so twisting out of shape or running together, they would ruin the vitrified ware. These clays are used for products burned at moderate temperatures, fusing in the neighborhood of 1800° F. They vary in amount of plasticity, shrinkage and porosity.

Along the rivers and streams of this State are deposits, of greater or less extent, of sandy clays, formed by the river. They often contain pockets of clear sand. Such clays are worked in a number of places, and make a good common brick. River clays are worked by the soft mud process by hand molding or simple machines. The more plastic clays may be worked by the stiff mud process, which is used in the larger plants.

In other places shales and clays are taken from the bank, where they are found in place as part of the stratigraphical series. The better grades may be used in the production of high grade pressed front brick or worked into ornamental patterns. They may be coated with a glaze burning into the enameled brick, which are often used in large buildings as an interior finish, though their use is limited on account of their cost (\$40 to \$80 a thousand.)

Terra cotta is made from carefully selected clays, which give uniform color, strong body, and burn without checking or cracking. In the manufacture of highly ornamental designs in terra cotta, a mixture of clays is used and the ware burned to a temperature of incipient fusion which would place this group under the

preceding heading in the classification. Drain tile are made from common brick clays and should burn to a soft, porous body, capable of absorbing water readily. The composition of some of the brick clays used in West Virginia is shown by the following analyses:

	Morgantown.	Clarksburg.	Charleston.	Elkins.
Silica	55.03	56.15	61.92	53.78
Alumina	26.76	23.48	23.32	22.57
Water and loss on ignition	8.01	9.91	7.05	6.48
Lime.....	0.86	1.25	0.42	0.18
Iron	8.11	3.26	3.38	5.54
Magnesia	1.76	1.55	0.78	1.00
Alkalies	3.31	3.15	3.18	3.69
Titanic acid.....	0.98	0.97	0.40	1.03

These clays are used in the manufacture of a very good quality of building brick, and have been vitrified, forming a good paving brick. The Morgantown and Elkins shales burn to a red color, while the Clarksburg and Charleston clays, with their low iron percentage, burn to a buff color. The Charleston clay is now used in the manufacture of buff dry pressed brick, very popular for fronts in the southern part of the State.

Gumbo Ballast Clay.

In a number of states of the Mississippi Valley, a peculiar heavy clay is used for railroad ballast. These clays, called *gumbo* have high shrinkage, 9 to 12 per cent., and the mass disintegrates under heat, causing the clay to crack into gravel, which makes it valuable for ballast.

The gumbo clays are fine grained, very sticky or tenacious when wet, giving a tensile strength of 370 to 410 pounds, or twice that of ordinary clays. It thus makes troublesome wagon roads in the wet season, and requires a long time to dry out. There is a high percentage of fluxes, 10 to 14 per cent., so the clay can be burned at low temperatures. This fusion is further aided by 2 to 5 per cent. of organic matter present. In Missouri the deposits are sometimes 20 to 60 feet in thickness, but on account of water held in the clay, they are only worked to a depth of six or eight

feet. The clay on chemical analysis shows in one deposit the following composition¹:

	Per cent.	
Silica	54.90	
Alumina	18.03	
Water (combined).....	6.90	
Moisture	6.72	
Iron	6.03	} 13.41—total fluxes.
Lime	2.88	
Magnesia	1.10	
Alkalies	3.40	
	99.96	

Slip Clays.

The slip clays are easily fusible clays, which are used to coat or slip stoneware, and thus give a smooth and uniform color to the ware. The fluxing elements range from 14 to 20 per cent. A good slip clay must fuse easily, give a uniform color, and not crack or check. In fusion, the slip clay forms a natural glaze, being burned into the ware.

In use the slip clay is mixed with water to form a cream, into which the ware is dipped. A number of slip clays are used in this country, but the one which stands in the highest favor is the Albany slip, of New York, a Hudson river clay which is shipped for this purpose to all parts of the Union. According to Wheeler,² the chemical and physical properties of the Albany slip are as follows:

	Per cent.	
Silica	56.75	
Alumina	15.47	
Water (combined).....	8.87	
Moisture	0.37	
Iron	5.73	} 18.08—fluxes.
Manganese	trace	
Lime	5.78	
Magnesia	3.32	
Alkalies	3.25	
	99.54	

The air shrinkage was 6 per cent., the fire shrinkage 8 per cent., or total of 14 per cent. Incipient fusion point was 1700° F., vitrification at 1850°, and viscosity above 2000°.

1. Missouri Geol. Survey, Vol. XI., p. 546.

2. Missouri Geol. Survey, Vol. XI., p. 355.

BRICK USED FOR STREET PAVEMENTS.

Progressive cities of the present day are known by the condition of their streets. A city with poor streets, or even with paved streets seldom cleaned or cared for, lacks the attractive appearance so characteristic of cities with well kept streets. There are cities in this State which have gone to the expense of paved streets which are much of the year buried under a pile of mud and waste, depending on the forces of Nature for a street-cleaning department, and this condition is a disgrace to the cities and to the city administration.

There are few cities of any size in this country that do not have some paved streets. Where good road materials in the form of rock are available, the smaller towns have the streets macadamized, and cities use this material on streets which are not subjected to heavy travel.

Streets are now paved with stone blocks, cobble stones, wood blocks, asphalt, cement, or brick. Where travel is very heavy, stone block makes a durable pavement, though very rough and noisy. Cobble stones were formerly extensively used in Northern cities, but in modern work are relegated to the alleys. Wood block, saturated in tar or oil, were used for a number of years, and on account of the noiseless character of the streets were regarded as a most valuable paving material, but their poor wearing quality and increasing cost have ruled them out as an expensive luxury. Cement streets, while used in a few cities, have not yet become general in use. Asphalt makes a smooth and attractive pavement, but is very apt to be slippery in wet weather, and is expensive in construction, with a constant demand for repairs after a few years service.

The brick pavement possesses a number of advantages over the paving materials above described. It is cheaper in cost of construction. When it is properly constructed it is durable, free from dust, and on account of the low absorption of vitrified brick it forms a sanitary paving material that can easily be cleaned.

The essential conditions for a good, durable brick pavement are: *A firm foundation; well vitrified, strong brick; proper construction and placing of the brick; a good filler.*

Many brick pavements are laid which do not fulfill these conditions, and the omission of some of them or a careless construc-

tion will lower the first cost. In some cities this is done to induce the citizens to pave the streets, where a higher cost would be prohibitive. Cheap construction is never economy, and leads to heavier repair expenditures. Cities are more and more appreciating these facts, and many have established by law a set of specifications which, if enforced, insure strong and durable pavements. The inspection of brick for pavements should be done by competent engineers, and not by a system of spoils to favored local politicians when these persons are not trained along these lines.

The foundation is often a source of future trouble in paved streets. The first brick pavements in this State were laid on tarred oak planks, set lengthwise across the street, and covered with a layer of sand. This expensive and troublesome method was supposed to give elasticity to the pavement and long life, but it has not fulfilled its claims, and has been abandoned. A gravel or broken stone sub-structure on which a layer of sand was placed, with the brick above, and the crevices between the brick filled with sand, represented an improvement, but such construction does not represent a modern, well laid pavement, though the method is still popular.

In a few cities of this State a layer of sand a few inches thick is placed in the street excavation on the clay or shale ground and the brick laid with no binder. Such cheap construction should not be permitted in any city, and is a waste of city money. The streets may stand well for a few years, but not for any length of time under ordinary conditions. In one city this method was claimed to be a perfect success, and yet in that same city one could see uneven streets and places where the pavement had settled a foot, forming regular chuck holes in a brick pavement.

Where a durable street pavement is to be constructed there should be a concrete foundation, with a sand cushion, on which the brick are laid. Good cement and broken rock should be used and the materials be well mixed and applied by experienced concrete men. On this are placed well selected brick, which are then well tamped and rolled with a heavy steam roller until the street is solid and smooth.

The filler of a brick pavement is now known by engineers, but not always by city boards, to be a most important subject. When the spaces between the brick are filled with sand, poor results are

attained. The old method of using a tar filler, while an improvement over the sand, is not as good as a cement filler made of one part of good Portland cement and one part sand. The additional cost of this cement filler is only a few cents per yard, and more than pays for itself in the life and durability of the pavement, with the added advantage of a smoother and more artistic street. Cities whose engineers have made a careful study of this paving question now include in their specifications a cement filler.

When pavements are not made in the manner outlined above, it is not fair to place the blame for poor pavements on certain brick companies. The fault is more often due to the method of construction than to the brick used. In our tests of paving brick of this State the brick which stood the lowest test was still a good paving brick.

In this State there are a number of companies making a very high grade paving brick, and there are also large deposits of good clay and shale for this work that are not used. If the cities and towns of West Virginia would improve their streets, using home made brick of good quality, they would make their cities more attractive for their residents and increase their industrial prosperity, at the same time building up a large brick industry, thus adding to the State's wealth. The subject of better streets in cities is a subject that deserves the most thoughtful attention of city boards, councils, and the voting citizens.

The great variety of uses of clay is shown in the following table, given by Ries in the Maryland report¹:

Domestic.—Porcelain, white earthenware, stoneware, yellow ware and rockingham ware for table service and cooking; stoves of majolica; polishing brick, often known as bath brick; fire-kindlers.

Structural.—Brick, common, front, pressed, ornamental, hollow, glazed; adobe, terra cotta, roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney pots; door knobs; fire proofing; terra cotta lumber; copings; fence posts.

Hygienic.—Urinals, closet bowls, sinks, wash tubs, bath tubs, pitchers, sewer pipe, ventilating flues, foundation blocks, vitrified bricks.

Decorative.—Ornamental pottery, terra cotta, majolica, garden furniture.

Minor Uses.—Food adulterants, paint fillers, paper filling, electrical insulators, pumps, filling cloth, scouring soap, packing horses' hoofs, chemical apparatus, condensing worms, ink bottles, ultramarine manufacture, emery wheels.

1. Maryland Geol. Survey, Vol. IV., p. 266.

Refractory Wares.—Crucibles and other assaying apparatus, gas retorts, fire-bricks, glass-pots, saggars, stove and furnace bricks, blocks for fire-boxes, tuyeres, cupola bricks.

Engineering Work.—Puddle, portland cement, railroad ballast, water conduits, turbine wheels.

PROSPECTING FOR CLAYS.

In certain sections of the State, especially near prosperous clay plants, there is much interest aroused in the location of new deposits of clay. From time to time samples of clay are sent to the Survey office with a request for information as to the value of the deposit. Such samples are often taken carelessly, so that they do not represent even average conditions. The clay is taken from the surface, where it is contaminated with surface wash, or from some point at shallow depth, and no attempt is made to determine the depth or extent of the clay deposit. Prospecting for clays in this manner has but little value, and it is a waste of time for the Survey to analyze and test such samples.

A few suggestions will be given in this section for the information of people over the State, farmers and others, who are interested in the development of clays, but who lack chemical and practical knowledge of the clay industry.

The present chapter includes a discussion of the uses of clays, and in the preceding chapters there were given details of the physical and chemical properties. Unless the clay is of a very high quality, adapted to fire brick or pottery manufacture, it will not pay to ship the clay very far to a plant, or haul it to a distant railroad point.

There is not a farm in the State but contains clay, good, bad or indifferent, in deposits of greater or less extent. A very small fraction of these deposits will ever be used, and only the best are worth an investigation. Common building brick, and even paving block clays and shales, are so widely distributed in this State along and close to the lines of railroad or waterways that deposits removed from such transportation lines will be valueless except for a small local trade. In some sections, this local trade is supplied with very inferior brick, made from impure clays, while good deposits in the same area might be used to greater advantage. A little careful prospecting work would there add money to the brick maker and beauty and durability to the buildings of the town.

At the present time it will not pay to haul even fire and pottery clays by wagon to a distant railroad point. The price last year for good fire clay placed on the car was one dollar a ton, and it could not be mined and hauled to the railroad in competition with this price.

Some of the finest clays in this State are to-day unused in Pendleton, Hardy and other counties, because of the lack of railroad transportation for the clay or the wares made from it. When the railroads penetrate these areas, as they will in time, these clay deposits will have a high value, where to-day they are counted as almost worthless.

When a clay deposit is located in a section where it might be utilized, its extent should be determined. This may be done by digging a pit to find its thickness, or by boring with an auger. If of shallow depth, its high quality will not make it worth developing.

Its area or surface extent may be determined by following the stratum from place to place in ravines where the streams have exposed the rocks and soil, in railroad or wagon road cuts, in wells, or by digging ditches and trenches. Some judgment is here required to be sure the clay is continuous from one exposure to another, and it should be tested in these places to determine whether the quality is sufficiently uniform.

The amount of cover or overlying material and its nature, whether hard or soft, is important in determining the value of the clay. Only clays of the highest grade will pay the cost of tunnel or entry mines. Mining of clay is avoided so far as possible on account of the expense and danger involved. In this State it would only pay for high grade fire clays. If the cover is very thick, or contains hard rock layers, the expense of removal of this useless material will be too great to permit the working of the clay.

The relation of the deposit to water conditions should be determined. If it lies in a low valley where the pit would be filled with water in wet weather, or where the natural drainage would collect in the openings, there would be added the expense of pumping, which may be prohibitive for profitable work. On the other hand, there should be a sufficient supply of water present for the uses of the plant. Labor conditions, cost of transportation by water or rail to good markets, supply and cost of fuel, must all be considered.

There is a more or less popular impression that the valuable materials for brick and tile must be present in the form of clay, so in prospecting, shales, often called soapstone, are neglected. In the early days of the paving brick industry in Ohio, the overlying shales were removed at much expense in one of the prominent paving brick plants, in order to secure the clay below. Later, the shales were experimented on, and proved a better material than the clay. In some States, nearly all the brick and tile are made from shales. In this State shales are used in many of the most successful plants. Not all shales are adapted to the work any more than all clays, but in the prospecting work they should not be overlooked.

In sampling clay or shale, care should be taken to secure an average lot. If a pit is sunk, samples should be secured from top to bottom, and also from a number of pits removed from each other. The sample lot should represent an average of the tract to be developed. The large quantity thus obtained is then ready to be tested at some brick plant or pottery where it can be made into ware and burned, and the character of the product determined. A brick made from a few pounds of clay taken from some one spot does not establish the character of the clay, though it may give some indication of the value. If the quantity of clay selected in this way is larger than required, it should be thoroughly mixed and divided, then, if necessary, mixed again and divided.

In looking for clays and shales in this State, it should be remembered that kaolin and china clays have not yet been found in any amount worth developing, and the great probability is they never will be. Local deposits of white bleached clay are sometimes mistaken for these high grade clays.

Fire clays for number one brick are rare, and when found in favorable localities deserve careful investigation. The clays under the coal seams are popularly called fire clays, but very often they are far removed from this class. The best fire clays are usually hard and flint-like, and when broken show a shelly fracture. After a few weeks' exposure to air and water they may slake to fine flakes, but not all hard clays are fire clays. Men of experience cannot be sure of fire clays until tested. A sample of fire clay sent to the Survey by an experienced man showed, on analysis, 16.74 per cent. of fluxing elements; very few clays in the State would equal this clay in fusibility.

Pottery clays at the present time are not well developed in West Virginia, but they will yet prove valuable. In some of the deposits of good pottery clays found in the present work the extent proved on investigation to be too small. A bed of pottery clay near some spring, the area, a few rods, perhaps, in diameter, would not justify the erection of a pottery.

It must be kept in mind that mere prospecting for clays will not prove their value; chemical analysis is not enough; the clays and shales must be tested physically, they must also be actually worked into finished product to determine their real worth. Without this preliminary prospecting the clays will not be available for such tests. The clay may make a high-class product, but its extent, thickness, amount of cover, surrounding conditions as outlined above, must be determined by careful prospecting.

It is hoped that this report on West Virginia clays will not only be of interest and value to the present clay companies of the State, but that it will also stimulate interest in this group of the State's natural resources and lead its citizens to search for new deposits. It is hoped that this section on prospecting will influence these persons to study all the conditions surrounding the clay deposits and to secure average lots of clay rather than to send a carelessly selected sample to some survey or testing laboratory.

A few simple tests will be given to aid in this preliminary prospecting work.

1. A small lump of clay may be roasted in a blue gas flame, as in a gas stove; if a red or brown color be given to the clay, the percentage of iron is high, probably four per cent. or more. Fire clays are low in iron.

2. By tasting a bit of the clay, bitter salts, alum, epsom, may be detected, or they may occur as white coatings on the outcrop of the clay in the bank. These salts are apt to form whitewash coats on the finished brick, injuring their appearance. By crushing the clay in the mouth the sand may be detected by the grit against the teeth. A rough determination of the amount of such sand may be made.

3. A study of the method outlined for plasticity in Chapter III, will show that an approximate idea of plasticity may be obtained by working the moist clay with the fingers. This is a good test for pottery clay, moistening the clay and finding whether it

can be worked into a definite shape and retain the form without cracking when dry.

4. A rough brick of small size can be made and easily dried, and a rough determination be made of its shrinkage. If it shrinks out of shape, cracks, or crumbles when dry, its value is very doubtful. For this test, the clay should be ground, thoroughly tempered with water, and dried slowly.

5. If carbonates of lime are present, a few drops of hydrochloric (muriatic) acid may be added, and will be detected by the effervescence or bubbling as the carbonic acid gas passes off. A better plan is to place a lump of clay in the small amount of acid, as the clay absorbs the liquid so rapidly the effervescence may be overlooked. Good fire brick are low in lime. If there be low percentage of iron present and a higher percentage of lime (about three times the iron), the clay product will burn buff. If the high percentage of lime be due to lumps of lime carbonate, the brick on burning will crack and warp. Very high percentages of lime are apt to ruin the clay. It is not always possible to predict the color of the burned ware from the color of the clay. Red clays will usually burn red, blue clays may burn red or buff. Dark or black clays are usually high in organic matter, and may burn red or buff. The color of clays is discussed more fully in the preceding chapter.

6. The slaking of clays or the crumbling down in tempering is tested by dropping a lump of clay in a cup of water. Some clays slake in a very few minutes, and so are easily tempered. Shales slake usually only after a long time, and require fine grinding.

These various tests can be made by any person, and while not conclusive, afford the basis for an approximate opinion on the nature of the clay.

CHAPTER V.

TECHNOLOGY OF THE CLAY INDUSTRY.

BRICK AND TILE.

MINING OF CLAY:

- Surface pits.
- Hillside quarries.
- Drift mines.
- Shafts.

HAULAGE:

- Wheelbarrows and Scrapers.
- Dump carts.
- Cars drawn by horses and by cable.
- Influence on location of plant.

CRUSHING:

- Crushers.
- Rolls.
- Disintegrators.
- Dry pans.

CONVEYORS:

- Belt.
- Bucket.

SCREENS:

- Inclined.
- Shaking.
- Rotary.

TEMPERING:

- Wet Pan.
- Soak Pits.
- Ring Pits.
- Pug Mill.

MOLDING:

- By hand.
- By machine.
 - Soft mud.
 - Stiff mud.
 - Repress.
 - Dry press.

DRYING:

Open yards.
Covered sheds.
Intermittent Tunnel Driers.
Progressive tunnel driers.
 Heated by hot air.
 Heated by steam.

BURNING IN KILNS:

Changes involved in burning clays.
Types of kilns:
 Up draft.
 Down draft.
 Continuous.

MINING OF CLAY.*SURFACE PITS.*

The smaller mud brick plants use river clays, or glacial clays, and in some western localities loess clays. These clays are found in the fields near or at the surface, or along stream banks. The deposits are often worked on a very small scale and intermittently as the demand may require. Such clay banks are to be found in nearly all localities, and the river clays are used for local trade in many towns of this State. The mud brick made are often of inferior quality due to the poor character of some of the clays and more often to lack of skill and knowledge in using them.

Some of the clay deposits are worked on a larger scale and handled by skillful and experienced operators, making a very fair grade of building brick, as will be illustrated in the description of West Virginia brick plants given in another chapter. Where the clays occur along streams, the deposit is worked by excavating the bank and working the clay back from the stream, keeping the floor of the pit above the water level of the stream, and also inclined away from the direction of working so as to give good drainage and avoid any expense of pumping.

The cover of soil, with its plant roots, rocks, or other troublesome material, is removed, unless so thin or having such characters that it does not interfere with the clay. This waste material is removed to a place where it will not interfere with future work, and after a portion of the clay pit is exhausted, the cover may be used for filling the abandoned workings.

In these small yards the clay is removed by pick and shovel and loaded into wheelbarrows or carts. The clays are apt to be

sandy and through the deposit are pockets of pure sand of greater or less extent, and often large and small boulders which must be carefully sorted out or they will injure the machinery, or if left in the brick will cause them to crack and break on burning. The pure sand is used at the plant for sanding the molds. The clay in these pits will vary in character becoming more sandy in places and more plastic in other parts, so the portions of different characters are mixed to produce the required product.

The cause of failure in some of the small plants is due to lack of knowledge and care of mixing the clays from different parts of the pit. Complaint is thus made at times that a certain brick plant is now making a very porous, brittle brick where it formerly made a higher grade. In such cases a little study and a few experiments might find the mixture for a better brick. Some operators come to believe that almost any clay used in any way will make salable brick. It is remarkable how successful some of these brick plants are, with the low grade brick manufactured. They thrive for a few seasons until competition closes their works.

As some of the surface clay plants build up a good market and add machinery, increasing their capacity, the clay pit is enlarged, carts take the place of wheelbarrows, and later cars and cable haulage are adopted. At first with use of wheelbarrows, the slope into the pit must be slight, but with carts and horses, it becomes steeper; and with the cable and car, the slope may have a steep angle, becoming nearly vertical.

In most of the surface clay banks of this State the clay is worked out with vertical walls to the pit except at the place where the slope is made to facilitate haulage. The depth of these pits is determined by the thickness of the clay where this is moderate. In deeper deposits it is determined by water conditions, the mode of transportation to the mill, and often by the extent of clay land owned. If the area under control of the company be large, the work is spread out; if small, the pit is worked deeper.

Water is often a source of trouble in pits, for the rise of streams or a season of rain will fill them, and the work be discontinued until the water seeps out or is pumped out by hand or steam power pumps. When the clays are soaked with water they are heavy and difficult to work and it requires a considerable period of time to dry them.

The river clays in this State are rather shallow in depth and are worked from four to twelve feet. The clay is usually broken down as needed; but in some of the larger pits a considerable quantity is broken down and wet with water, tempering it before removal to the plant. The clay may be broken down by driving a series of wedges along the bank a short distance back and prying it over with bars, or it may be broken down with the pick. These clays are seldom blasted.

HILLSIDE QUARRIES.

Where shales or bedded clays are worked, the methods of mining are somewhat different. If possible, a location for the quarry is selected above the level of the plant so as to secure the advantage of gravity in transportation. The clay or shale is worked along the outcrop giving a long and often narrow opening. If the materials are soft, they may be removed in the same way as the river clays, by pick and shovel, but when they are more compact, it becomes easier and more economical to blast.

The cover, if thick and not of use in the clay mixture, is scraped off to one side; but if it consists of clay or weathered shale and free from boulders, it is broken down and mixed with the other parts of the bank. A row of vertical holes is drilled along the top of the bank and the shots placed which will break forward large masses which are further broken by pick and sledge. From the shattered material, the larger masses of foreign matter, such as lime, pyrite nodules, sandstone fragments, and boulders, may be separated and thrown to one side. The broken shale or clay is then loaded and hauled to the plant.

It is better to leave the shale or clay for a time exposed to the weathering action of the atmosphere. This action gives the material a finer grain and adds to its plasticity. Many non-plastic clays thus become plastic. The West Virginia flint clays are non-plastic when first mined, but many of them become quite plastic after weathering. Soluble impurities which might produce a coating or wash on the surface of the burned ware are in large part removed. The shale and clay become more uniform in texture and they are more readily crushed and tempered, thus saving in cost of power and wear on the grinding machinery.

It is well in view of these facts to work a large face of the quarry and so have more material blasted down than is needed in

order that it may remain exposed to the air for a time before use. When the dull season of winter approaches a large quantity of shale or clay can be blasted down and remain through the winter ready for next spring's work. It is a good practice followed in a few West Virginia shale pits to break up the material and spread it out where it can be stirred up by a disc harrow from time to time. There is one plant in this State where the improvement in product from this treatment was so marked that they now keep a large space covered with the shale which is stirred every few days and left for weeks before use. The bench system of quarrying the shales is not much used in this State even where the height of the bank reaches 30 feet. When this method is used the benches are shallow, and made merely to facilitate the work of blasting.

The total thickness or run of the bank is used in the manufacture of building brick. In the manufacture of tile and paving brick it sometimes becomes necessary to watch carefully the characters of the clay or more especially the shale, and to mix material from different parts of the quarry in certain definite proportions. The clay or shale may be quite sandy in one place and more plastic in another. This is done by taking a load from one place, and the next from another place, or two loads or more, according to the proportion determined. In a large quarry an increase in capacity with reduced cost of labor is accomplished by the use of a steam shovel, but none is used as yet in this State.

DRIFT MINES.

Clays and shales under a moderate thickness of cover are mined by the above methods of stripping the cover. If the cover is of such thickness and character as to make the work too expensive, ordinary clay and shale pits will be abandoned and the work be discontinued or new openings be made at other more desirable locations.

In the case of the more valuable clays adapted to the manufacture of sewer pipe, fire and paving brick, the clay is very often overlaid by heavy rock strata, making the stripping method impossible. It then becomes necessary to mine the clay by drifts, slopes, or shafts, the same as coal. When possible, the entry is driven so that the stratum dips toward the mouth, as this gives a natural outward grade for the cars and facilitates drainage. In

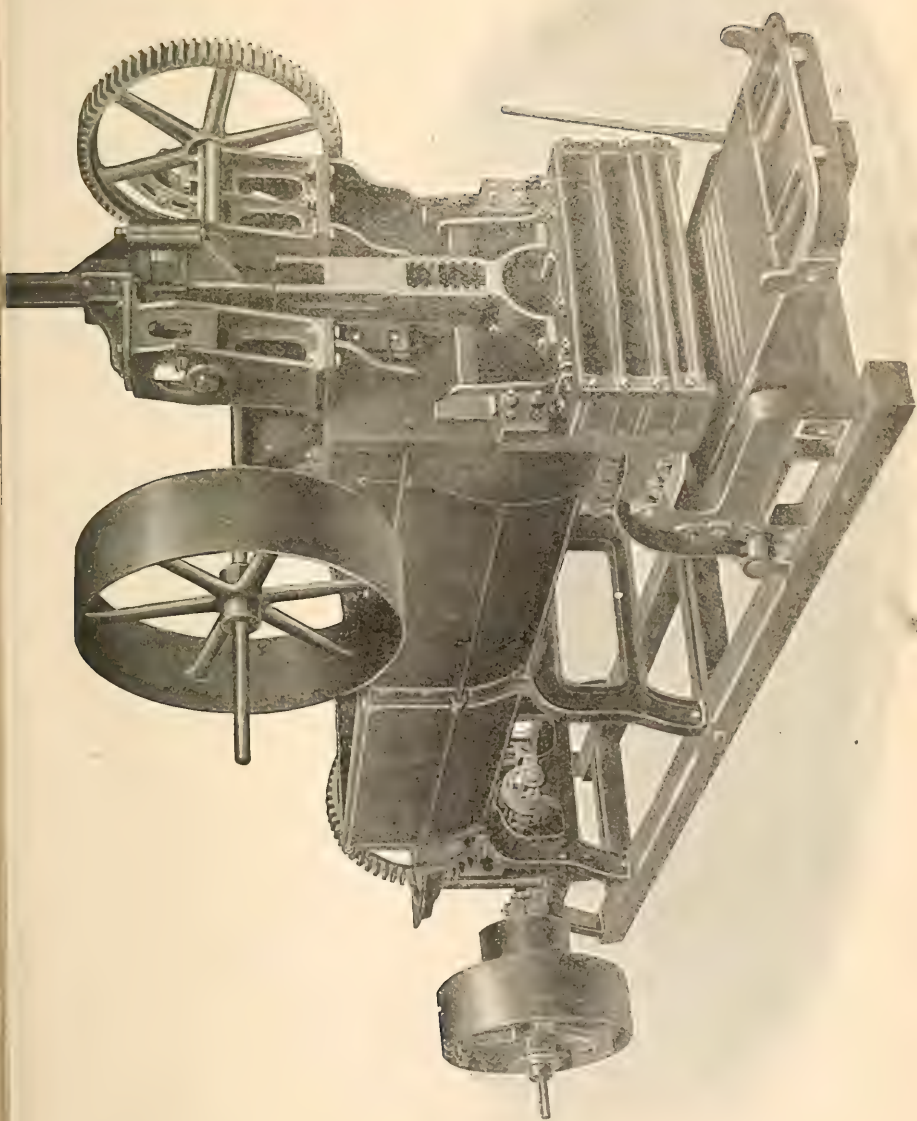


Plate VI.—Potts Horizontal Soft Mud Brick Machine.

nearly all clay mines water is a source of trouble, and where the mine dips into the hill pumps are required, thus adding to the expense of mining. The mine is usually worked high enough to reach a solid roof, as a clay or shale roof will be treacherous and increase the danger of the work.

These mines are much more expensive to operate than the surface pits or quarries on account of the timbering required in the outer portion where the rocks of the hillside are weathered and the pillars required in the inner workings. Timbering of clay mines becomes a most important problem for as the clay is exposed to the action of air and water, it softens and the weight of the overlying layers causes it to press out and close the entries and rooms, permitting the roof to cave. There is also the increased cost of trackage and repairs on track. There is the extra need of air shafts, and often in the large mines, air fans and pumps. The capacity of clay mined per man is less and so adds to the cost of mining. Further, mine work requires skilled miners who receive higher pay than quarry laborers, together with the added cost of lights and powder.

The miners are paid usually by the ton of clay mined, the weight being estimated from the known capacity of the cars, or the cars are weighed near the tipple. Two miners work together as a crew and at New Cumberland mine about 25 tons of clay a day, and three shifts are worked in twenty-four hours. The heavier blasts are set off at night, but minor blasts are set off through the day whenever needed. With good draught, the smoke from the small blasts clears out in a short time. The clay is blasted out like coal except that the seam is seldom undercut, the breaking up of the clay under blasting being here an advantage, where it would be a detriment in coal mining. The drilling is done by hand drills, no power drills are used in this State up to the present time.

The clay seam is opened by a number of entries to facilitate working by a larger number of men and cars. As the entry is driven farther into the hill, laterals are made, and it is eventually worked on the room and pillar system. The different hillside entries become connected and the arrangement is in reality a double entry system. Air shafts are driven from above and the ventilation carefully arranged.

Some of the best clays in West Virginia are mined by drift mines, as at Charleston, Piedmont, Thornton, Hammond, and New Cumberland. At the last place where the work has been in progress the longest period of time, the entries reach 2,300 feet in length. The clay reaches 12 feet in thickness and is overlaid by 30 inches of good coal with sandstone roof and floor. Both clay and coal are mined and used at the works.

In nearly all the West Virginia clay mines the drifts are above the level of the mill. The clay is loaded in mine cars and these are pushed or hauled over a nearly level grade to the top of the tipple or incline, and there dumped or taken down the incline to the plant.

SHAFTS.

The shafting method consists in sinking a vertical shaft down to the clay seam and running entries from this into the clay. The method could only be used with profit on the highest grades of clay adapted for china or high grade fire brick in a section of the country where such clays could not be obtained in any other way. The method is not used at any place in this State.

HAULAGE.

In the opening of a surface clay pit for a small hand mold brick yard, the clay may be hauled to the molding space in wheelbarrows, a slow and laborious process only permissible for very limited output. On a little larger scale the clay is taken up in wheel scrapers holding eight to fifteen cubic feet and hauled to the plant and dumped near the pug mill. This is a cheap and convenient method requiring a small force of laborers. If the clay is too tough for this work it is ploughed and then removed by scrapers, or it is shoveled into two-wheeled dump carts holding 1,500 to 2,000 pounds, a method which requires a little more labor, but is adapted to tough clays which must be loosened by the pick or plough.

As the plant is increased in size, and the pit is worked on a larger scale, and especially in quarries where there is a grade down to the plant, wood or steel tracks are laid and the clay is loaded into small mine cars pushed by hand or hauled by horses or mules to the works. When the clay is to be worked on a

large scale this is the economical method for increasing the capacity.

The cars are usually made of heavy wood, or even of iron, though no iron cars are used in this State. They hold three-fourth to three cubic yards (2,800 to 6,000 pounds) and are made in three styles, end dumping, side dumping, or bottom dumping, the last is usually automatic in its action and as it reaches the end of the track at the plant the clutch which holds the doors shut in the bottom of the cars strikes a projecting rod and is released. The first, or end dumping car, is the pattern used in this State in most of the quarries and mines above the level of the plant. The car is run out on a tippie which is operated by a long pole fastened down by a loop. When the door of the car is opened and the pole released the clay is dumped to the level below.

Where the track is on the level of the crushing floor or where the clay is to be dumped in long bins, the side dumping cars are used. The cars may be used single or in trains. The latter system is used where there is long haulage. As the pit reaches greater depth and the slope becomes too great to use horses, a cable is attached and the cars are thus hauled up to the plant. In one West Virginia plant electric motor power has been used to haul the cars from the mine one-half mile distant.

When the clay bank is not very high above the plant the cars are run out on the tippie and dumped so that the material rolls down to the grinding shed. If the distance is greater and the elevation of the mine is high above the plant, an incline is used with double track or switches placed so the cars can pass. The loaded car going down pulls the empty one up, the cars being controlled by a cable passing several times around a drum which is held by a friction clutch. If the material comes from a lower level, the cars are raised to the plant by a power hoist.

In the location of a clay working plant it is very desirable to have the plant and clay pit near together and so decrease the cost of haulage. They should, however, be far enough apart to avoid danger to the plant and workmen from blasting and also from the caving of the bank from the effects of blasting and weathering. Rock slides which sometimes occur in clay and shale quarries should not endanger the plant.

The nearness to railroad, water supply and drainage must be considered. The distance from markets and resulting cost of

transportation is an important problem, and also the distance from town and supplies, as in many sections this distance has an important influence on labor. Laborers prefer to live in or near town rather than at a more distant point.

CRUSHING.

The clay from the surface pit as hauled to the plant consists of coarse and fine material in the form of large and small lumps. In order to secure a uniform product for molding, these lumps must be broken, but usually no special crushing machinery is required, as the clay is sufficiently broken in the process of tempering. The process of tempering will be more rapid if the material delivered to the tempering machine is already fine in grain, and the capacity of the plant will be increased by first crushing the clay.

Where flint clays or hard shales are used, it becomes necessary to crush the material to particles of small and nearly uniform size. As has been shown, fineness of grain adds to amount of

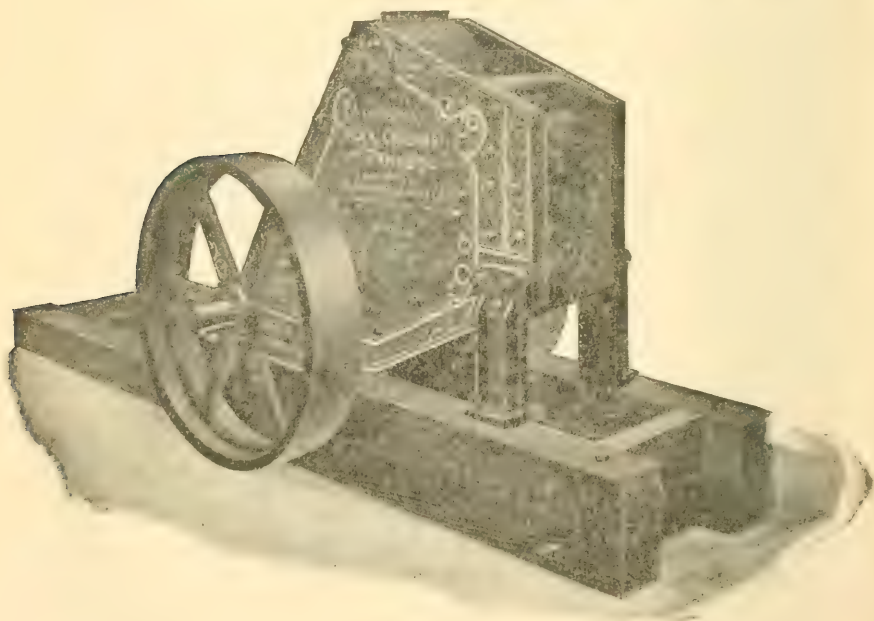


Fig. 6—Champion Clay Crusher.

plasticity developed in clays, and it also gives a more uniform product.

Another important result of crushing the materials is their more thorough mixture. The clay or shale varying in character in different parts of the pit or mine, when crushed together become more or less thoroughly mixed and this gives average results which are more constant. A thorough mixture of finely ground clay or shale will make better common brick; and in the higher grade products, the thorough mixture becomes essential to successful work. Brick made from variable clays not thoroughly mixed would differ so much in their characters that it would be difficult to mold them uniform, so in drying they would shrink in different amounts, and in burning would further shrink in variable degrees and would not vitrify equally. The result would be brick from the same kiln of different sizes, colors, and hardness, a miscellaneous assortment of low market value.

CRUSHERS.

It is therefore a matter of the greatest importance in successful brick and tile manufacture that the raw material be thoroughly mixed and of even texture. These results are to be attained to a large extent in grinding and finally in tempering. There are two methods in common use, and the clay or shale must be prepared in part by both methods, the dry and wet, the former is the crushing method, the latter includes both crushing and tempering. Soft plastic clays are in some cases only treated by the wet process.

The surface clays, and in nearly all quarries and mines the clays with or without weathering, are ground in crushers of different makes and types. Of the fifty plants visited in this State, fifteen use crushers, twenty-two use dry pans without crushers, and thirteen treat the clay in pug mills without dry crushing. In the use of the dry pan on hard clays, the blocks are broken by a sledge, which is a slow process and the hard lumps in the dry pan cause heavy wear and tear on the rollers and floor plates.

Crushers used for grinding clay are of three types: *Jaw*, *roll*, and *disintegrator*. Two types of jaw crushers are used in this State, the *Champion*, and *Blake*. The former machine has two heavy iron jaws on which are fastened chilled charcoal iron dies, forming the wearing surface, so placed as to form an open

V-shaped box. One of the jaws is stationary and forms the front of the machine, the other is a swinging jaw with a short pendulum motion. It is swung from a steel shaft above and operated from below by a tumbler working on an anti-friction

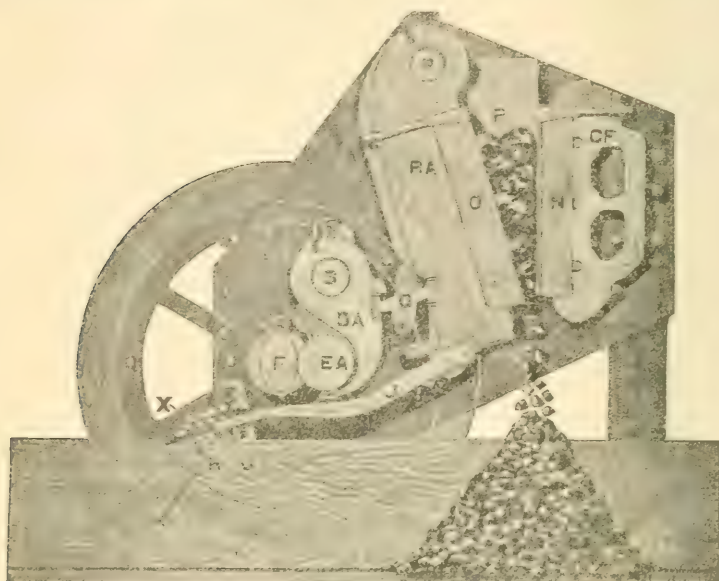


Fig. 7.—Champion Clay Crusher (sectional view.)

roller which is moved by an elliptical cam. This arrangement gives a back and forward motion to the swinging jaw through a connecting toggle joint. The movement opens and closes the aperture at the base of the V-shaped box, and the size of the opening is regulated by the size of the toggle joints, which for clay work are seven to eight and one-half inches long, crushing the rock from three-fourths to two and one-half inches in size. The form of crusher usually found in brick plants will crush twelve to fifteen tons of clay an hour, requiring about fifteen horse power.

Another type of jaw crusher used in three of the West Virginia plants is the Blake, in which the principle of operation is similar, except the swinging jaw is hinged below and operated from above.

The Gates crusher has a cylindrical hopper in which revolves a cone-shaped shaft with corrugated surfaces. This crusher is illustrated in plate XXVI. in Part III. By an eccentric attachment, this shaft has a gyratory movement, and the capacity is greater than in the preceding types. This machine is used in many of the stone quarries of the state, but not in the brick plants. When used on clay the ordinary size machine will crush twenty to one hundred tons an hour.

ROLLS.

The roll crushers are made in a variety of styles. In one form two or four rolls are used of the same size, about fourteen inches in diameter and twenty-one inches long, with the rolls revolving at different speed. The size of the ground material is governed by the distance of the rolls apart, which is regulated by set screws. The smooth rolls will crush small masses of dry clay, but if in large lumps or hard masses, the process is slow. Wet clay will stick to the rolls and seriously impede the work. Rolls are recommended especially for shales and dry, lumpy clays.

DISINTEGRATORS.

The more common type of roll crusher is the disintegrator, in which one of the rolls is modified by having short teeth, or grooves, or raised bars attached to it.

In the Potts disintegrator used in this State, one of the rolls is twice the diameter of the other, the large one is smooth and acts as the feeder. The small roll has six grooves in the surface into which hard steel bars are fitted and made removable so they can be reset or renewed when worn. The large roll is twenty-four inches in diameter and makes twenty-five to forty revolutions per minute, while the small roll is twelve inches in diameter and runs at 800 to 1,000 revolutions per minute. The clay is broken as a result of the differential speed and the cutting action of the steel bars. The large roll is driven by belt and the smaller one by friction, and the space between the rolls regulating the size of the ground material is adjustable.

Where desired a compound machine is made with disintegrator above to break the large lumps and hard masses, which fall to the smooth rolls below where the material is ground to flour. The capacity of the disintegrators varies according to the length

of face of the rolls which are made from twelve to twenty-four inches, giving a crushing capacity of clay sufficient for 20,000 to 60,000 brick a day.

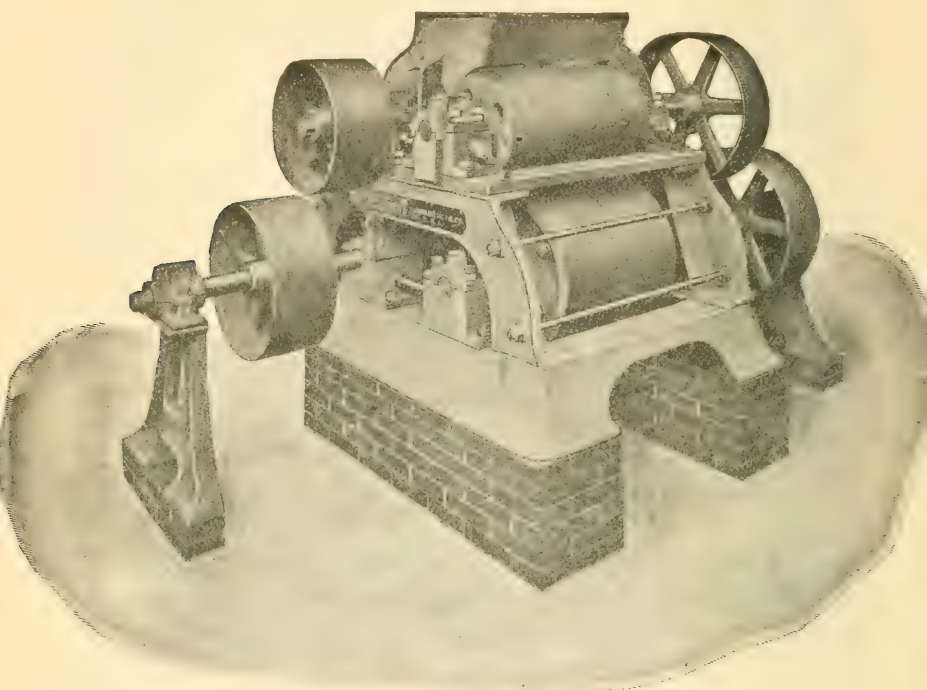


Fig. 8.—Martin Roll Disintegrator.

In the Arnold-Creager disintegrator, in use in a few of the West Virginia plants, the rolls are roughened in diamond shapes, so as to render them more effective in grinding, and the fast revolving cylinder or grinding roll has projecting bars or cutters. The slow cylinder or feed roll has adjustable bearings so as to regulate the size of particles. In the average size machine the rolls, which are of the same size, are nineteen inches in diameter, with nearly same length of face. The fast roll makes 400 to 600 revolutions per minute, and the slow roll, forty to fifty revolutions. The machine will grind on average clay enough for 35,000 to 45,000 brick a day.

In the Martin disintegrator the rolls are made of equal size, fourteen inches in diameter, with twenty-four inch face, and both

rolls are fitted with steel lugs or pins which work alternate with those on the opposite roll. The pins are set so as to be easily removed and new ones inserted. This crusher is illustrated in figure 8.

In the Steele & Sons' disintegrator the feed roll is smooth, hard chilled and arranged in three sections, reversible. The bearings are adjustable to determine required distance between the rolls. The small roll has six adjustable steel cutting bars. The large roll runs thirty-five revolutions per minute, and the small roll 700 to 800, giving a capacity of clay for 20,000 to 100,000 brick a day.

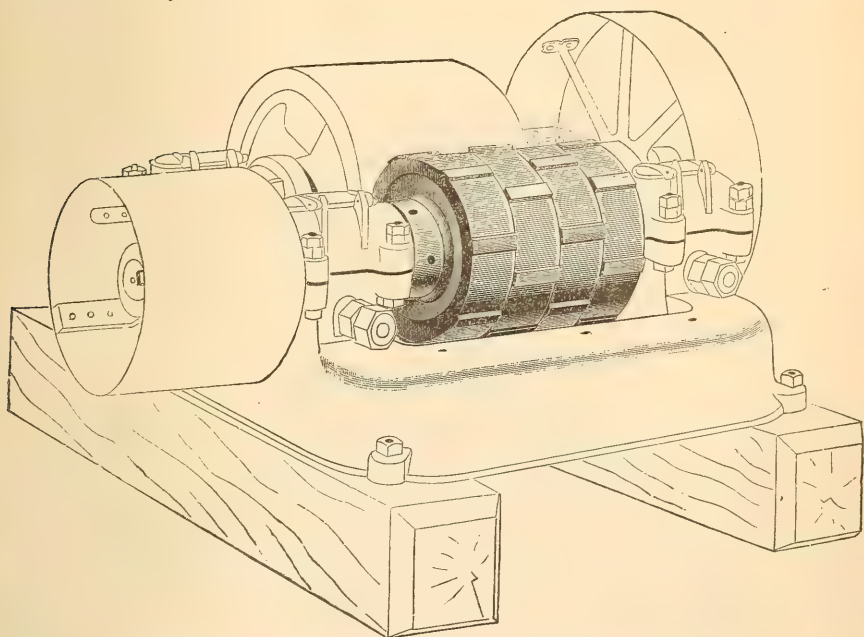


Fig. 9.—Raymond Clay Disintegrator. (Interior view.)

The Raymond disintegrator has an adjustable feed roll which in the machine with a capacity of 4,000 to 6,000 brick per hour, is twenty-four inches in diameter, with eighteen inch face and travels at speed of 125 to 150 revolutions per minute. The cutting roll is sixteen inches in diameter, running at 750 to 800 revolutions per minute. This cutting roll is made in sections having projecting teeth which are set alternate with each other so they do not

strike the clay at the same time along the length of the roll. The sections are interchangeable and reversible. The interior construction of this machine is shown in figure 9.

The American Clay Working Company disintegrator is made in three sizes and has the large feed roll twenty-four to thirty inches in diameter, with a face fourteen to twenty-four inches. The high speed smaller roll is provided with projecting steel cutters and is twelve to eighteen inches in diameter with a speed of 450 to 600 revolutions per minute. These machines will grind clay for from 1,500 to 5,000 brick per hour.

Another type of disintegrator does away with the grinding and crushing surfaces and uses the force of impact in breaking the clay or shale into fine particles. In the Stedman type, there

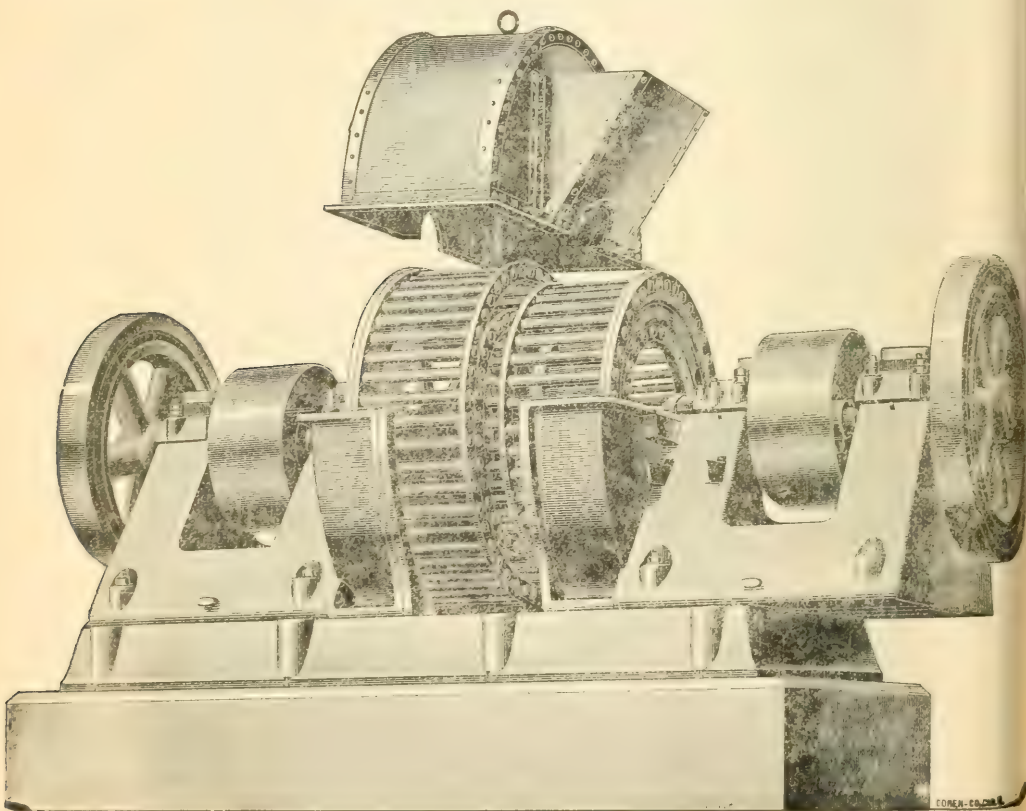


Fig. 10.—Stedman Clay Disintegrator. (Cover raised.)

are two or more cages formed of round iron bars reinforced by iron rings and secured to heavy case circular discs. The bars of one cage project between those of the opposite cages. The cages revolve at high speed in opposite directions, and as the clay or shale is fed through the hopper at the side, the material is thrown with considerable force against the bars and from one set to the other so that it is broken by impact against the bars and the impact of the particles on each other. This machine is illustrated by figure 10.

The speed of revolution is determined by the character of the clay and the fineness desired. In plastic clays the cages are run at 600 and 650 revolutions per minute. The usual size of mill for clay work is the forty-inch run at 400 and 500 revolutions per minute, giving a capacity of 2,500 to 4,000 brick per hour. If finer grinding is desired, the speed is increased.

A second type of impact disintegrator is the Williams hammer pulverizer (see figure 11). The hammers are attached to bars set on discs so as to fly outward from the center of the shaft, which revolves at high speed. These hammers strike 30,000 to 36,000 blows a minute and the machine will crush 25 to 400 tons of clay a day. Adjusting screws permit an easy regulation of the size of

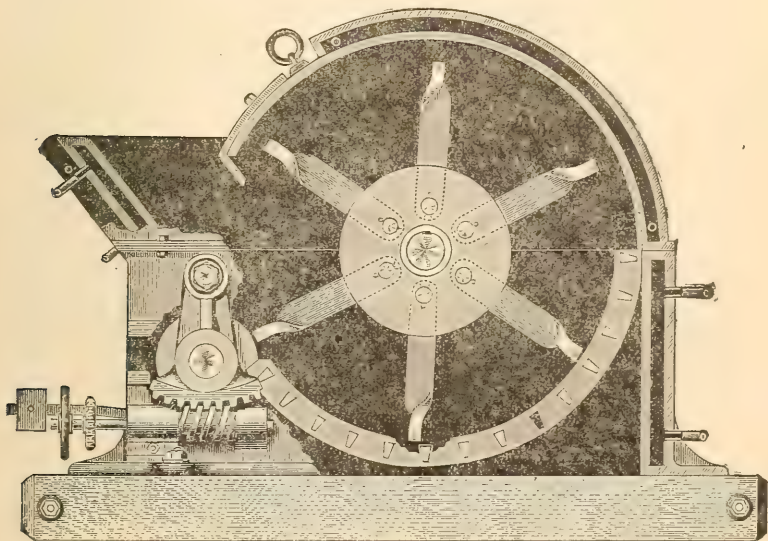


Fig. 11.—Williams Clay Pulverizer.

the material which when completely broken passes through the screen plates which are concentric with the path of the hammers. The Williams machine, with forty-eight hammers, is used at one plant in this State to break the shale.

DRY PANS.

When crushers are used, the material is sometimes conveyed directly to the brick machine or to the pug mill; while in other plants it is further ground in *dry pans*. In nearly one-half of the brick plants of this State the clay and shale are ground in dry pans without any preliminary use of crushers or disintegrators.

This machine consists of a heavy cylindrical metal pan with a floor of screen plates over which roll two heavy wheels or mullers. The pans are made five to nine feet in diameter with steel rims fourteen inches high. The bottom of the pan near the central shaft is solid and over this roll the mullers, while the rest of the floor of the pan is composed of sectional screen plates supported by substantial arms. The plates are made of white iron with size of perforations varying with fineness of material desired, but they average about one-eighth inch in diameter.

Scrapers are attached to the sides of the pan to throw the material under the mullers, and the ground clay is thrown outward by the centrifugal force and passes through the perforated screen plates to a receptacle below, where it is pushed to the point of discharge into an elevator or conveyor. The pan is attached to a vertical shaft which rests below on a support or *step*, and above is attached to the cog crown wheel, which is driven by a cog pinion wheel, set on the driving shaft. This arrangement revolves the pan under the rollers. The Stevenson dry pan, used in several plants in this State, is illustrated by plate III.

Considerable care is necessary in the construction of the under support or *step*, as this supports the entire weight of the machine above and it must permit easy movement of revolution. This bearing must be as nearly dust proof as possible, for the dust will wear by friction and ruin the bearing. It must also be supplied with abundant oil for the lubrication of the surface. In one type of dry pan this step consists of a hardened tool steel toe on the end of the shaft, with a step plate forming the bottom, and between these two surfaces runs a convex hardened steel thrust plate. The whole is surrounded by a dust proof casing

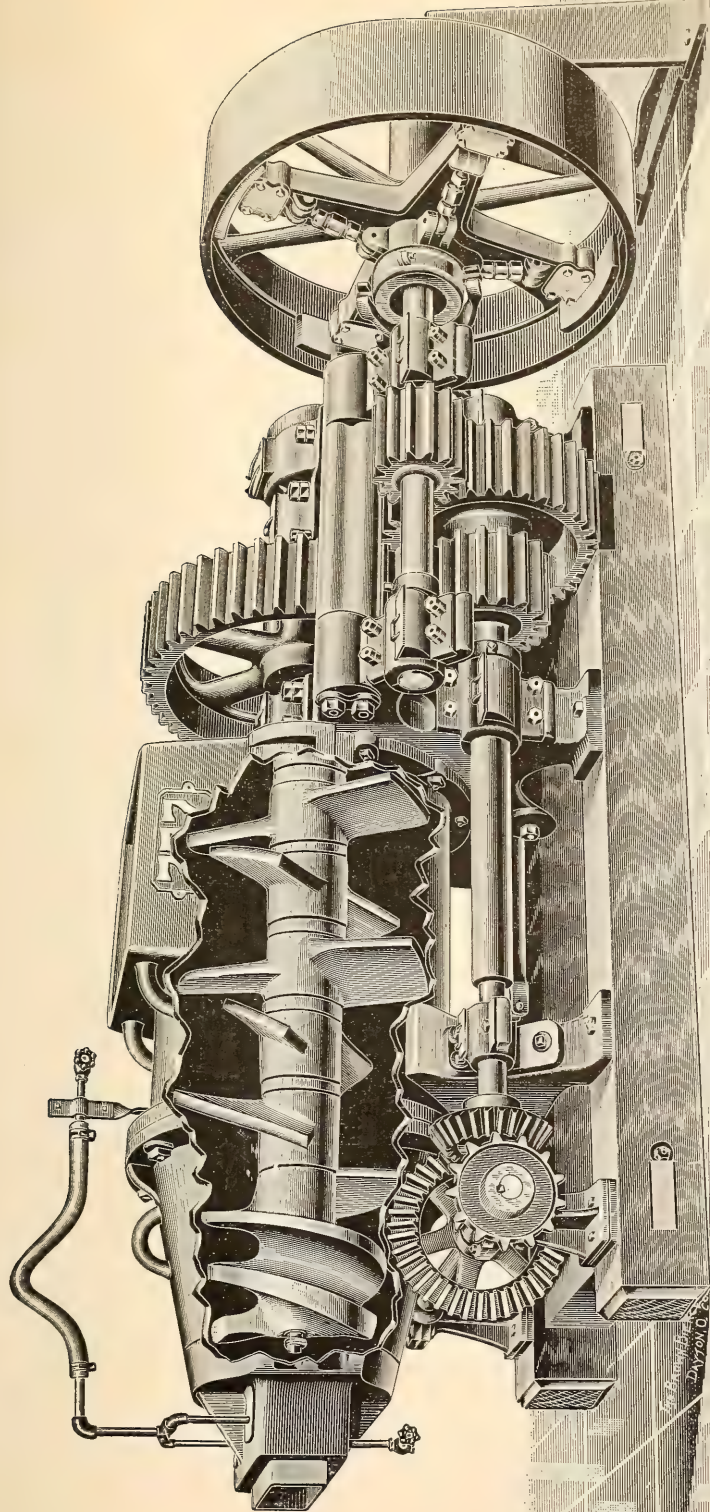


Plate VII.—Raymond Auger Stiff Mud Brick Machine—Sectional View.

with a packing ring around the shaft kept filled with oil through a pipe from the oil reservoir.

In another type the step consists of two hard chilled discs with distributing oil grooves, and between these discs is a patent phosphor-bronze plate to decrease friction, heating, and wear. The oil passes down through a perforation in the vertical shaft.

The rolls or mullers are attached to horizontal shafts. The two mullers are mounted on one continuous shaft, or better, on two independent shafts which remove strain and permit both rollers to move on their flat surfaces even when large lumps may hold up one of the rollers. The ends of the shafts are held down by heavy springs and so suspended that the rollers usually do not touch the floor of the pan when this is empty. The springs permit the rollers to rise and fall according to the size and quantity of clay lumps beneath. In other types the mullers are supported by chains or by vertical rods with spring bearing at the top to decrease the weight on the pan.

The rims of the rollers are made of chilled car wheel iron which can be removed from the center mass, and this in turn can be removed from the hub. In the nine-foot pan the rollers are forty-six to fifty-two inches in diameter with nine to twelve-inch face, and weigh three to four tons each. In capacity a nine-foot pan will run 25,000 to 60,000 brick in ten hours.

These machines, on account of their weight, necessary rigidity, and constant jar, must be supported by very substantial frames. The supports are made of heavy iron, each side cast in one piece, and the two connected by a heavy cross beam, the whole structure firmly bolted together. This frame for a nine-foot pan weighs about four tons, giving a weight of the pan complete of fifteen to twenty tons. Wood frames made of twelve by twelve-inch timbers are used on some dry pans, but they are not as satisfactory as the iron frames which are used in nearly all the modern plants.

CONVEYORS.

The clay from the crushers and dry pans is carried to the screens and storage bins by conveyors. These labor-saving devices may be used wherever the material is to be removed from one part of the plant to another.

If the clay is not to be carried to a much higher level, the

conveyor is a belt or rubber apron. They are made sixteen to thirty inches wide with side dashers or flanges to prevent the clay from falling off, and they are supported at frequent intervals by rollers. The belt is arranged so as to travel over end pulleys 110 to 120 feet a minute. Cross strips are sometimes added to the belt when the angle of inclination is increased.

If the incline is very steep or vertical, bucket elevators are used. In this type there is a series of iron or steel buckets ten to twenty inches in width fastened to a belt or sprocket chain. The buckets take up the clay below and as they turn over the pulley at the top automatically discharge into a spout to the bins or to the screens.

SCREENS.

When the clay is crushed by the methods described, the material is rarely ground to uniform size. In the dry pan method the screen openings become unevenly enlarged by wear, and portions are sometimes broken out allowing coarser particles to pass through. This result is even more noticeable in the crushers and disintegrators.

It then becomes necessary to screen the material and return the tailings to be reground. The screens are made of heavy wire or perforated metal, the latter being usually preferred on account of its smoother surface and better wearing qualities. The clay screens are made in three general types: inclined, shaking, and rotary.

The *inclined* screens are in common use in brick plants and are cheap and easy of construction. They are merely boxes ten or fifteen feet in length and about thirty inches wide, inclined at an angle of twenty-five to thirty degrees, and with the bottom covered with a wire or perforated metal screen. The clay from the dry pan or crusher is delivered by conveyors to the top of the screen and rolls down over it by gravity. The steeper the angle of the screen the finer the material passing through and the greater the proportion of the tailings.

The tailings pass into a chute which leads back to the dry pan and the fine material passing through goes to the storage bins located above the pug mill. While this type of screen is cheap in first cost and in repairs, it takes up considerable space, is limited in capacity, so that in a large plant there must be sev-

eral screens. It also requires constant attention to keep the screen free from the accumulation of fine clay which tends to clog the meshes.

In order to economize space and also to secure greater capacity, *shaking* or vibrating screens are used. These screens are made single or double, eight to twelve feet in length, thirty inches wide, and set at low angles. They are fastened by a pivot at one end, or swung by chains, or on transverse rods and pins which work back and forth.

The material is brought to the top of the screen by conveyors and the screen is made to vibrate longitudinally or transverse, the latter type being more common, which throws the clay from side to side and by gravity on the slight incline, the clay slowly works down to the base of the screen where the tailings are discharged. These screens are more expensive than the preceding type and require a small amount of power. The constant jar necessitates a substantial building and they also require attendance to keep the meshes open.

Rotary screens are made in cylindrical or polygonal form. The frames are made of steel or wood which are covered with the screening material and the whole made to incline downward at a slight angle. The perforations of the screen are about one-eighth inch and the cylinder turns with twelve to twenty revolutions per minute.

Clay is fed into the screen at one end, the fine material passes through into a box below while the coarse material passes out at the lower end of the screen. In some types of circular screens cleats are fastened along the inside to carry the clay upward so the material in falling gives impact to the particles, adding efficiency to the screen.

In the polygonal types there are six to twelve sides, and the angles made serve to hold the clay and carry it upward to fall again on the screen. To prevent the fine clay from settling in the meshes and clogging the screen, brushes are sometimes attached to the outside, or automatic pounding and jarring devices are added. These screens require close attention and also considerable power, but they have a larger capacity per day than the other types and do not require much space.

TEMPERING.

The crushing methods described are adapted more especially to dry clays and shales, and the purpose is to grind the clay so as to make it finer and uniform in grain.

In the process of clay manufacture it is necessary to develop the plasticity of the clay by adding water to it, and to bring the whole mass to a uniform condition. This operation is described as tempering and is accomplished by several methods and appliances.

WET PAN.

One common method of tempering clay used for pottery and sewer pipe manufacture, but seldom in brick work, is the wet pan. The construction of this pan is similar to the dry pan except the bottom is solid, and the mullers usually have a narrower tread and as a rule smaller pans are used.

The clay is shoveled into the pan and water is thrown in from buckets or hose until a sufficient quantity is added to temper the clay to the right consistency. The clay is then removed by a long handle shovel pivoted to rim of the pan. The wet pan grinds and tempers the clay in one operation, but its work is intermittent as the finished charge must be removed before new material is added.

For special purposes the rollers are modified and made narrow faced and fluted shaped so as to have a serpentine tread. There are four of these rollers so placed as to cover the entire floor of the pan in a complete revolution. This machine increases the speed of tempering and thoroughly cuts and works up the clay.

SOAK PITS.

In some of the soft mud plants of this State the clay is mixed and tempered in soak pits and wooden pug mills. A pit is excavated three or four feet deep and six to eight feet long, lined with planks. The clay and sand are mixed with water by shovels until the pit is filled, when it is left to stand over night. The clay is next removed and molded, or more often it is shoveled into a square wooden pug mill which is an open box with a vertical central wood shaft to which are attached a number of wood or iron cutting bars. From the top of the shaft extends a long beam or arm which is turned by horse power.

The clay is shoveled in at top and is cut and mixed by the revolving arms, finally issuing through a gate in the bottom ready for molding. This is a common method of tempering in small hand mold brick yards, as the apparatus can be built by home labor at small expense.

RING PITS.

An improvement over the soak pit is the ring pit where the clay and sand are mixed with water in a specially constructed circular pit and thoroughly mixed and cut by revolving wheel set on a shaft operated by horse power.

The round pit for a six-foot wheel is made about eighteen and one-half feet in diameter and three or four feet deep, lined with boards. The wheel weighing about 600 pounds cuts by the rim, which is sometimes in two sections, and by the spokes. The wheel travels the circle and is so arranged by rod and pinion that it is drawn automatically back and forth on the shaft, changing its position with each revolution. It requires one hour to temper clay for 10,000 brick under average conditions. There are usually two or three pits, so clay may be worked from one while the other is being tempered.

One crude type of pit in one of the small yards of the State consisted of a circular trench about two feet wide and same depth in which turned an ordinary wagon wheel set on a long arm and operated by one horse, but the ring pit is not used to any extent in West Virginia.

PUG MILLS.

In the larger brick plants these crude methods of tempering are usually replaced by the machine pug mill. The pug mill manufactured by the American Clay Working Machinery Company is shown in plate IV. If the clay is soft it may be fed directly to the pug mill, but in hard clays and shales the material is first ground in crushers, disintegrators or dry pans. This fine ground material is then ready to be tempered with water preparatory to the molding process, and no machine equals the pug mill in popularity for this work. These machines are usually made horizontal and either separate from the brick machine or made a part of it. They are made with closed or open tops, the latter is usually preferred as the operators can then watch the clay and determine whether more or less water is needed.

The box is made of steel or wood, varying in length up to fourteen and eighteen feet, the usual size being eight to ten feet. A nine-foot pug mill is about thirty inches in diameter, semi-cylindrical in shape. Through the center passes a horizontal shaft to which are attached thirty to thirty-six pugging knives, which are set at an angle to the shaft and have a spiral arrangement so as to work the clay to the discharge end where the opening is controlled by a movable gate. The clay is added through a hopper at the opposite end and the water flows through a pipe, the amount is controlled by the operator, who is on constant watch.

This work requires an experienced man as the clay must have the proper working consistency, which is readily altered by the addition of too much or too little water. The trouble sometimes experienced in brick molding machines where the bar of clay is broken or cracked is often due to the condition of the clay from the pug mill. If the clay is too wet, the brick will be easily injured by handling, will require a longer time for drying and the resulting shrinkage may seriously injure the size and shape of the product.

The length of mill required depends on the character of the clay, uniform and plastic clays requiring a shorter mill. The time required for the clay to pass through the mill depends on the length of the mill and angle of the blades to the shaft. A nine-foot pug mill will temper an average lot of clay sufficient for 30,000 to 45,000 brick in ten hours. The work of these mills is continuous and they afford a ready control on the tempering process. They are compact, requiring a small space. The weight of a nine-foot pug mill is about three tons.

If the clay is a hard refractory clay and requires more thorough pugging, a closed top mill is used, where the top is closed by sectional cast iron covers, and the discharge end is closed so as to cause more thorough cutting and mixing by the revolving knives. Pug mills are usually set on a raised platform above the brick machine, so the tempered clay falls down into the hopper of the machine.

In the manufacture of soft mud brick and in some stiff mud machines, the pug mill is combined with the brick press. On the Horton and also Potts soft mud machines, the combined pug mill is twelve feet long, thirty inches wide, and thirty-six inches deep, giving ninety cubic feet capacity sufficient for 2,000 stand-

ard size brick. In the stiff mud and combination machines the pug mill is six to eight feet long and the clay passes from the pug mill directly to the auger of the brick machine. This combination saves space and the expense of a platform above the machine. The building can be made lower and use shorter elevators. In most of the plants in this State the pug mill and brick machine are separate.

MOLDING.

After the clay is thoroughly ground and tempered by some of the methods described, it is ready for molding into brick. The molding is accomplished by hand or machine. In the smaller soft mud plants and in the manufacture of fire brick, the molding is done by hand.

The hand mold is a wooden box with partitions forming spaces for the brick. The frame is bound with iron bands and in some cases the box is lined with iron or steel. They are made so as to have the long direction of the brick transverse to the length of the box, or sometimes arranged so the brick stand end to end in the box. The ordinary size mold is eight and one-half inches long, four and one-eighth inches wide, and two and one-half inches deep. The molds hold from three to six brick and have handles at each end so as to be easily carried from one place to another in the process of the work, and are illustrated in figure 12.

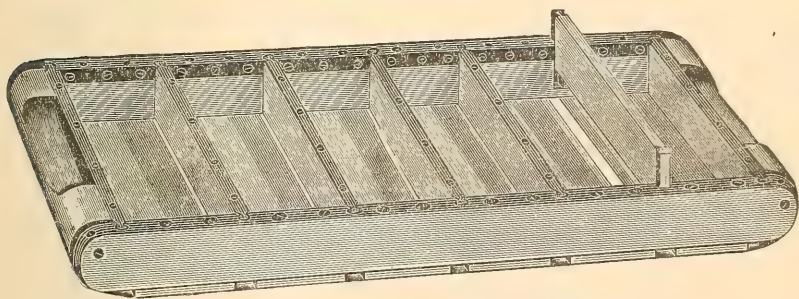


Fig. 12.—Martin Hand Brick Mold.

In using the hand molds the brick maker sands the boxes by throwing in a fine, sharp, clean sand, to prevent the clay from adhering to the walls of the mold. He then takes a lump of tempered clay a little larger than required to fill the mold and forces it into the mold, pressing it firmly into place, striking off the top of

the mold even with a wire or more rarely a cutting knife. The mold is then carried to the drying yard or floor and dumped by turning the mold over.

In the smaller yards one man hauls the clay from the tempering pit to the molding table, molds the brick and carries them to the drying floor. Where several molders are employed the clay is usually brought to the table by another set of laborers, and removed by the same, or by others. The molders are usually paid by the 1,000 brick, and expert molders can make 3,000 to 5,000 brick a day.

In the manufacture of fire brick it is essential that the brick should have a uniform structure without lamination or other defects. They should also be loose in structure rather than compact. These results can best be accomplished by hand molding, so that most of the refractory brick is still molded by hand even in the larger factories. Soft mud machines can be used for this work, but the hand molded brick are held in higher favor by the trade.

Hand molded brick lack the smooth surfaces of machine molded brick, and not being subjected to any great pressure in manufacture, are not popular for front walls of buildings, but are adapted to interior walls, chimneys, and like uses. The method is cheap, not requiring expensive machinery and is adapted to small yards which are run for a part of the season making enough brick to supply a year's demand. In some parts of the State these small yards are operated once in two or three years. With care a very good grade of common brick can be made, but in some of these plants the brick is made almost worthless from lack of care or want of knowledge of the business, and one can there see parts of kilns of brick gradually crumbling to pieces because no one is willing to buy the soft fragile brick.

SOFT MUD MACHINES.

If the brick plant is to be operated on any scale supplying a more or less constant demand, it becomes more economical to use machines. The soft mud machines are made after a number of plans, both horizontal and vertical. The molds used are similar to the hand molds, each holding usually six brick. The molds are sanded by hand, throwing the sand into the dampened molds, shaking it around in them and dumping the excess; or the boxes

are sanded by automatic machines which save labor and increase the capacity.

In the machine sanders, a wheelbarrow load of sand is placed in the cylinder, and in some types an endless chain or belt carries the mold boxes down into the sand filling them and brings them up on the other side reversed, so the surplus sand drops out and the molds are taken off and placed in the brick machine. The sander is regulated so as to deliver the molds as rapidly as used by the brick machine.

The vertical type of soft mud machine is a square box, in the center of which revolves a vertical shaft, to which are attached horizontal tempering knives, working on the principle of a pug mill. The clay is forced to the bottom mainly by its weight, and then is forced into the press box by two wide blades. The press box is at the front of the machine, and the pressure is exerted vertically on the clay by a plunger, which works on the power shaft above. This machine is illustrated by the Martin brick press in Plate V.

The empty molds are inserted from the side back of the press box, two molds being in the machine at the same time. The front mold when filled with clay is automatically pushed forward and the back mold comes into place under the press box, and a third empty mold is inserted into the machine. In some machines there is an automatic striker to cut off the surplus clay from the top of the mold box. In other types this is struck off by hand with a two or one-handled knife. The knife should be kept ground and have an even edge, or it will tend to work down into the mold at the uneven points, and so tear out masses of clay, giving very ragged surfaces to the brick. This trouble seems to be more common with the long two-handled blade than with the shorter one-handled knife. A slightly diagonal thrust with the knife works better than the straight movement. These machines have a capacity of 25,000 to 50,000 brick in ten hours, requiring ten horse power and weigh four to five tons.

The machines are adapted to use of horse power by attaching a sweep about twenty feet long, to which one or two horses are hitched. A team of horses travelling two and one-half miles an hour will make 110 revolutions, and as the machine turns out three molds of six brick each, or eighteen brick at one revolution, this method would give a capacity of nearly 2,000 brick an hour.

In the horizontal type the pug mill is horizontal, and connects directly with the short vertical press box, in which the clay is pressed into the molds by an arm and lever arrangement. The pug mill is eight to twelve feet long, and the clay in the process of tempering is pushed forward and delivered to the press, there to be forced into the molds. After the mold is filled it is pushed forward, and another mold takes its place, as in the other types. The horizontal soft mud machine is represented in Plate VI., which shows the Potts type of brick press. A convenient accessory to the soft mud machines is a revolving brick dump table, which holds four to six pallets, on which the molds from the press are emptied, and from which the pallets can be removed and carried to the drying floor.

In operating the soft mud machines with an automatic sander, ten to eighteen mold boxes are used. The work requires one man to feed and temper the clay, one man or boy to attend to sanding the molds, and placing them in the machine, one man to strike off the clay and remove the molds, one man to place the pallets and load the cart, and two or three haulers. Soft mud bricks have five sandy surfaces, and the sixth is rough from the striking off of surplus clay. They are quite uniform in texture, and more or less porous, so withstand frost action. Clays which are very plastic can be worked by this method, which could not be otherwise used. The cost of equipment is less than for stiff mud machinery, but the capacity is limited, and more laborers are required. Where very compact bricks are required, as for paving purposes, the pressure is hardly sufficient, though this can be remedied to some extent by repressing.

STIFF MUD MACHINES.

In this method the clay is worked into a stiff mud which is plastic, but not pasy, and this mud is crowded through a die forming a bar which must be stiff enough to hold its shape even when subject to strain. The old style stiff mud machine operated by plunger, but in most of the modern types an auger is used to crowd out the clay.

The auger machine consists of a short pug mill, the knives attached to a horizontal shaft, which terminates in an auger. Plate VII. shows a sectional view of the construction of the Raymond auger machine, and Plate VIII. shows the Giant auger

machine, made by the American Clay Working Company. The clay is thoroughly tempered before being fed into the machine through the hopper. It is there crowded forward by the revolving knives to the auger, which presses it through the die, issuing as a compact bar of clay. If the brick are to be side cut, this bar has the length and width of the clay. If the brick are end cut, the bar has the width and thickness of the brick.

The clay worked by the auger method has a tendency to become laminated, which is in part removed by the pressure in forcing through the die. Very plastic clays will retain this structure, and are not adapted to this process. Friction caused by the clay passing through the die will make the edges of the brick broken or ragged unless overcome by using water, steam, or oil, as lubricant in the die. With proper precautions the bar should have square corners and smooth surfaces.

Sanders are added to some machines to sand the surfaces of the bar as it emerges from the die. All the surfaces are thus coated or only the bottom. This prevents the clay bar sticking to the conveyor belt, and the brick from sticking to each other when piled on the car or in the dry room, and is claimed to give a better color to the brick when burned.

In the ordinary size auger machine, the clay chamber is twenty-four inches in diameter, the shaft carries six double pug-ging knives and an auger fifteen inches in diameter. This machine will make 4,500 to 6,000 brick an hour, requiring forty to sixty horse power, and weighs six or seven tons. In the smaller machine the clay chamber is eighteen inches in diameter and weighs three tons, requiring twenty-five to thirty horse power. Its capacity is 2,500 to 3,500 brick an hour. The smallest auger machines are made of a weight of 1,600 pounds, requiring eight to ten horse power, and will make 6,000 to 8,000 brick a day.

CUTTING TABLES.

The clay bar is carried from the die by belt conveyor to the cutting table, where it is side or end cut by wires fastened to a steel frame and operated by hand or is automatic in its action.

There is a great variety of wire cutting arrangements which have ardent supporters among brick operators. They may be grouped under two styles, those in which the wires pass from side to side and rotating cutters.

The cutting table usually moves with the column of clay and at the same velocity, so that the wires make a vertical cut. In the simple type of cutting table, the wires are hung vertical in a frame, which is drawn back and forth across the clay bar, by a hand lever or by a simple automatic device. Two designs of cutting tables made by the American Clay Working Company are shown in Plate IX.

The revolving reel or rotating cutter is made in a variety of styles by different companies. In one type the wires are fastened across the open top of U-shaped frames, which stand in the position of the spokes of a wheel and attached to a hub. As this wheel is revolved, the wires are forced through the clay bar, cutting it into the width or length of the brick.

In another type, there are two circular end frames joined by a central axis or shaft, from which three sets of wires pass to horizontal bar supports on the circumference. Twelve brick are cut at a time by a downward stroke of the wires as the reel is revolved. The stroke of the wires may be vertical, or the wires are so arranged as to strike the corner of the bar and cut diagonally through it. This method of shear cutting the bar is easier on the wires, and is claimed to give a smoother cut surface.

The automatic cutting tables are fitted with more or less complicated systems of levers and cogs, which carry the cutting wires through the column of clay when it has moved the proper distance, and draw the table back to repeat the operation. The tables are arranged so as to cut four to seventeen brick at a time, and can be adjusted to make end or side cuts of the thickness desired. The wires must be as fine as possible, with the necessary strength. As any hard obstruction in the clay will break them, and since after wear they break easily, the fastenings must be made so they can be quickly replaced, and this without stopping the machine.

The portion of the table on which the bar of clay moves is polished smooth, and guide rollers are used at the side and sometimes underneath, which are kept abundantly supplied with oil. The cut brick are removed from the side of the table on pallets which are in some types automatically shoved under the brick; or the cut column passes over another conveyor belt which travels at a higher rate of speed than the table, thus separating the brick

so they can be easily picked up and loaded on cars for the drying room, or placed in repress machines.

REPRESS MACHINES.

Paving brick are usually repressed, and some companies use the repress on building brick. By this method the previously molded brick are placed in the repress machine and subjected to high pressure.

These machines are built in compact and heavy form. The brick from the conveyor belt are placed on the feeding table and automatically pass into the mold boxes, where they are subjected to pressure exerted by a plunger from the top or from both top and bottom. The lower plunger, after the relief of pressure from above, continues the upward movement until the brick are even with the top of the mold, where the brick are automatically pushed forward to the off-bearing belt, from which they are loaded on cars. In capacity the double mold machine will turn out 1,000 to 2,800 standard size brick per hour, requiring one to two horse power. This machine weighs 7,500 pounds, and will give a pressure of 45,000 pounds per square inch, and the amount of pressure can be adjusted so as to give any amount required. The mold boxes are supplied with oil from a reservoir, thus preventing brick from adhering to the mold and forming a smooth surface. The Victor repress of the C. W. Raymond Company is shown in Plate X.

The object in repressing brick is to make the brick denser and stronger; to stamp trade-marks, or the name of the company or brick on one side; to give smoother surfaces and shape the corners and obliterate the rough cut sides of the brick where these are side cut; to mark one or both sides of the brick by special patterns, as in paving blocks or sidewalk brick. In the manufacture of front building brick the repress method has been, in the past, popular, but it is now replaced to considerable extent by the dry press method.

In the manufacture of paving brick the repress product has been generally regarded as superior to the auger brick without repressing. It gives a smoother and more compact surface, which would lower absorption. It has been claimed that any lamination in the brick due to the auger would be in large part removed by the repress. The impression that these brick are

superior to the other brick not repressed is so strong in certain sections that in many contracts the brick not repressed will be refused.

A number of careful tests have been made in the last few years to determine whether repressing paving brick improves their strength. None of these have shown any marked improvement in strength or wearing qualities of repressed brick, and in some brick the results showed a decrease in these qualities. It is claimed by some authorities that the repress method breaks the structure given by the auger, but without adding any improved structure, and so weakens the bond of the clay particles.

A number of experiments were tried to determine the value of repressing brick, by the National Brick Manufacturers' Association a few years ago, and the results of this work were given as follows¹:

"Makers of paving brick should assume that their plain wire-cut brick are superior to the repressed brick until they have proven, by careful comparison, under identical tests, that the assumption does not hold good in their case.

"If repressing is necessary to meet market conditions, the maker should perform the operation so as to cause a radical breaking up of the auger machine structure, and the production of a new and characteristic structure due to repressing. If this is done, the probabilities are that no falling off in quality will occur, and actual gain in strength may frequently result."

In order to reach this result, the brick must fit loosely in the mold so that the old structure can be destroyed.

DRY PRESS MACHINES.

The front pressed brick of fine grain, uniform texture, and smooth surfaces, so highly prized in the construction of fine buildings, were formerly made by the repress method, but this method is now replaced to a very great extent by the dry press.

In the processes of brick manufacture thus far described the clay is thoroughly tempered with water. In the dry press method, the clay or shale from the bank is broken by harrow or other instrument and placed in sheds for a few weeks to temper. This is termed the sweating process, and permits the moisture to permeate the whole mass. The clay is nearly dry, with only eight to fifteen per cent. of moisture, so that when pressed by the fingers it will slightly cohere. This clay is then finely ground and screened to a fine flour.

1. Report of N. B. M. A. Committee on Technical Investigation, p 92, quoted in Iowa Geol. Survey, Vol. XIV., p. 209.

The nearly dry clay flour is stored in a bin above the hopper of the brick press, the two being connected by a flexible canvas tube. The dry press is constructed in heavy compact form similar to the repress, and operated by steam or hydraulic power. A system of heavy levers moves the plungers with great compressive force and the top and bottom plungers moved toward each other in the mold. These molds are automatically filled and the clay is compressed under very high pressure. The molds have perforations to permit the air contained in the clay to escape, and molds and plungers are usually steam-heated to prevent the clay adhering to the surfaces. By the arrangement of the levers operating the plungers the pressure is exerted and partially relieved alternately with a final heavy pressure, thus permitting all the air to be forced out of the clay without injury to the structure of the brick.

After the brick is compressed the upper plunger releases its hold, and the lower pushes the brick up to the level table, where it is automatically pushed forward to the off-carrying belt, and clay for another set of bricks automatically fills the mold boxes and the work is repeated. The dry press brick are usually burned in the kiln without any preliminary drying. A four mold dry press machine weighs fifteen tons, and requires ten horse power, giving a capacity of 16,000 to 24,000 brick in ten hours. The Boyd dry press is a popular type of machine, and is illustrated in Plate XI.

Hand power dry presses operated by means of a screw or lever are used especially for ornamental tile and brick. Better results are attained on these designs with hand power, as the operation is under more complete control, the number of angles and corners in these designs render them liable to adhere, and so mar the outline. One man can make on these presses about 2,000 brick a day. The dies are readily changed, and an almost endless variety of patterns can be made. Such ornamental designs make effective cornices, trimmings, and are popular for interior mantels.

At the present time dry press brick are made only at Charleston, in this State. The Isaacs Kanawha river yard has been making a very fine quality of buff dry press brick which may be seen in a number of buildings in Charleston. These brick are equal to the Ohio product which is shipped into the State.

There are other good deposits of this buff burning clay in this section not yet developed. This should become an important industry in this area, and the brick could be shipped to all portions of the State and to Eastern markets.

Pressed front brick and ornamental molded brick are shipped into the State from other sections. There is no reason why our plants should not supply this home demand, and even ship such brick into other markets. Some of the clays, especially in the southern part of the State, are adapted to such work, and it would well pay some of the West Virginia plants to work along this line.

DRYING OF BRICK.

The molded brick, except in the dry press method, contain a very considerable amount of water, which has three sources. The *water of chemical combination*, which varies from four to ten per cent. in the clays examined, and can be removed only at high temperatures. The *hygroscopic moisture*, which clay naturally absorbs from the air, and which can be removed at the temperature of boiling water, but when removed it is taken up again on exposure to the air. The water added in tempering the clay, united with the moisture in the clay when delivered to the plant, is often called the *water of plasticity*, and varies in amount from fourteen to thirty-five per cent.

In tempering clays for brick manufacture, the amount of water required varies with the character of the clay, but the average quantity in West Virginia clays is about 20 per cent. There would be, then, in 1,000 standard size brick about 1,400 pounds of water, which must be removed by drying, or in paving blocks, which weigh green or unburned, twelve and one-half pounds, 2,500 pounds of water in 1,000 blocks.

To illustrate the amount of work to be done in the evaporation of water in one paving brick plant in the State, there are twelve tracks in the tunnel drier with twelve cars to the track, each car holding 500 paving blocks, which weigh 9.2 pounds each when burned. When the tunnel drier is filled with green brick, there would be 84 tons of water to be evaporated, or seven tons to each tunnel. This water is evaporated in twenty-four hours, so that it becomes important to use methods of drying which will give the greatest efficiency for a given amount of fuel.

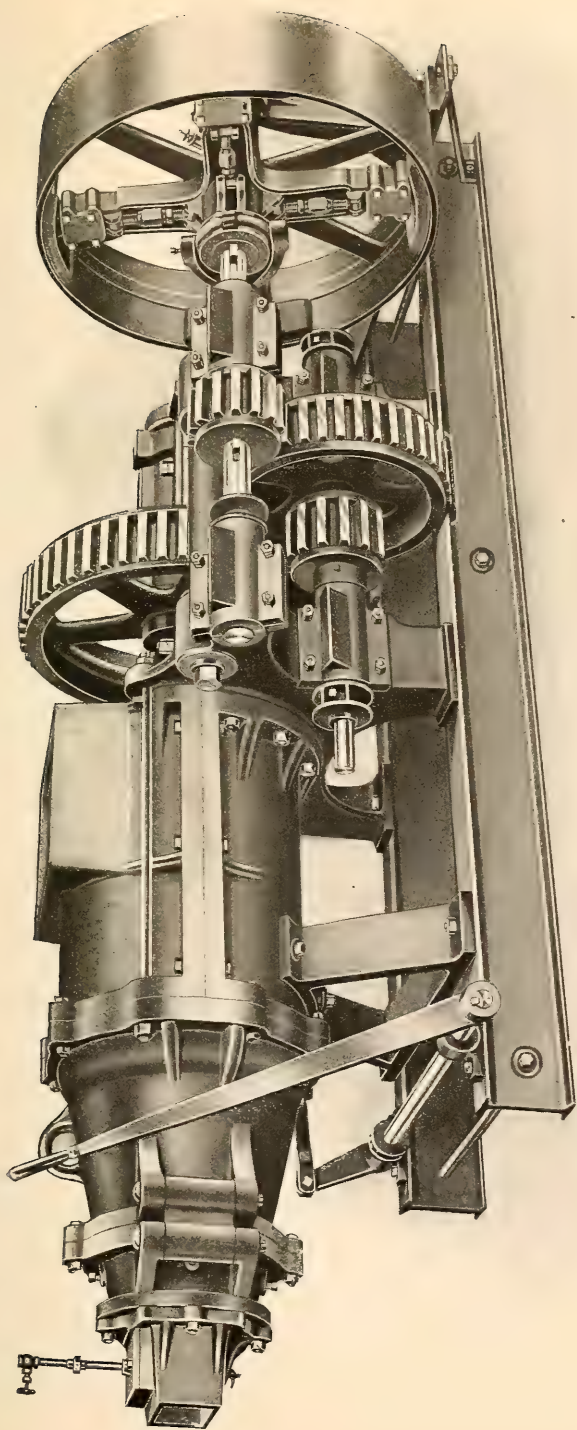


Plate VIII.—Giant Auger Stiff Mud Brick Machine.

Taking the average heating value of West Virginia coal, it would require 114 pounds of coal to evaporate the water from 1,000 brick under theoretical conditions, where the air was constantly renewed, and the temperature kept at 212 degrees Fahrenheit, but these conditions do not exist in these driers. Such a temperature used on the green brick at first would ruin the product. In practice it is found that about twice this amount of fuel is required, or about 230 pounds for 1,000 brick, or 2,500 to 3,000 cubic feet of gas.

If the molded brick, with the water of plasticity, were placed directly in the kiln, their soft condition would prevent stacking the brick in high courses; they would be more or less injured in handling, and with the greatest care in burning they would be cracked and warped by the escape of the water and the shrinkage of two and one-half to ten per cent., and by the pressure of overlying courses.

It therefore becomes necessary to dry the brick before burning in kilns. The two important factors in drying are heat and circulation of air. When there is a poor circulation of air around the drying brick, the air will become saturated, and will not take up more moisture, and may even deposit moisture on cooler portions, so the air must be renewed. The air in the drier becomes heated, and if driven out with a low percentage of moisture, will escape with its load of heat, which is wasted, and represents a waste of fuel.

There are several methods of drying the green brick, which will be considered under five heads:

1. Open yards, by direct heat of the sun.
2. Covered sheds, by the air.
3. Drying floors.
4. Intermittent tunnel driers.
5. Progressive tunnel driers, heated by hot air or steam.

OPEN YARDS.

One of the oldest and simplest methods of drying brick is in the open yard, where the brick are exposed to the direct heat of the sun and the flow of natural air currents. In former times it was the only method used, and at the present time it is a popular method in the small soft mud plants. The fuel is cheap, but the method is expensive in loss of brick. There are not many plants

in this State that use these open yards. In one plant the method is used with stiff mud brick, but another season this will be abandoned for the tunnel system.

A level yard is selected near the molding room, and this is scraped and rolled to give a smooth, hard surface. The brick are carried in the mold boxes or on pallets by hand or cart and dumped on the yard on the flat surfaces of the brick, thus making a series of rows of five or six brick each. After resting in this condition for half or three-quarters of a day, the brick are turned on edge and left over night. In favorable weather they will be dried sufficiently to stack in hacks, ten to fifteen courses high. In this shape they are left to dry for ten days to three weeks. Board covers are used to protect the brick from the rain.

The time required for drying depends on the nature of the clay, but more especially on weather conditions. In case of rain, the hacks can be protected by the covers, but the brick not hacked are very apt to be injured or ruined. The brick are at the mercy of the elements, over which the operator has no control. A considerable amount of labor is required in turning and hacking the brick. The method cannot be used in the rainy spring nor in the late fall and winter, when the brick would be subjected to freezing temperatures. It is essentially a summer method, thus restricting the working season of the plant, and must give a limited capacity unless very large yards are used, which will then make long carriage of the brick to the yard and from yard to kiln.

Many clays will not withstand the changing temperatures involved in this process. The green brick are placed under the direct rays of the sun and at night are cooled down, to be heated again the next day. The air may be quiet a part of the time and in rapid circulation at another time with strong dry wind, causing rapid drying, and therefore rapid shrinkage. The losses from these causes and from rain are sometimes very high, amounting to one-fourth of the output, and the average loss is a costly one. The method is being replaced to a large extent in these smaller plants by the covered shed system.

COVERED SHEDS.

The brick from the hand or machine mold may be dumped on wood or steel pallets, holding five or six brick, and these may then be stacked in drying racks, under a shed roof. The pallets

commonly used are made of wood, either in one piece or made of slats, leaving air spaces, which is a better design. In a few plants steel or iron plates are used.

The racks are made of a series of posts, with cross arms to hold the pallets in eight to twelve vertical courses, one row on each side of the posts, and as long as desired. The racks are protected by a shed roof, which projects over the pallets, and the rows of sheds are far enough apart to permit a brick car to pass between. The roof shields the brick from the direct rays of the sun and the open arrangement of the racks permits the air to circulate around the brick, which are thus dried by air currents rather than by the direct heat of the sun.

In one plant the racks are made to hold 15 pallets, placed end to end on each side, and are seven pallets high, thus holding 210 pallets each, or 1,260 brick. Twelve to twenty-four sheds are used, giving a capacity of 15,000 to 30,000 brick.

In other plants, with larger racks and a greater number, the capacity ranges from 50,000 to 150,000. The roofs are sometimes made sectional, and hinged so as to be opened to the sun's rays after a few days' preliminary drying. In favorable weather, the brick are dried in seven to ten days. The danger of injury from rain is to a large extent avoided, and the danger of too rapid drying producing cracks and checks is greatly lessened. The process, like the open yard, is limited to the summer season, but the space required for a given capacity is much less. The open shed pallet system of drying brick is used in a large number of the soft mud plants in this State. In a few plants this method is used in summer, and a dry floor is provided for fall and winter use. In the pallet system the brick only require one handling of the individual brick, and that, after drying, in the removal at the kiln.

In the Scott system, used in three plants in the State, the pallet sheds are closer together, and the roofs connected and made with movable covers. The roof is also made of canvas, with a patent removing apparatus, which enables one person to uncover a yard of 200,000 brick in ten minutes. The Scott patent car takes the pallets of brick, and by raising a lever lowers the deck of the car and places the pallets on the racks in the driers. When dry the brick are moved in the same way. With two cars two men can handle 30,000 to 40,000 brick a day.

DRY FLOORS.

The brick may be dried on wood or brick floors, the former with currents of air of ordinary temperature, or artificially heated, passing over them. The latter, heated from flues beneath or by steam or hot air.

In one type the fires are built below the brick floor at one end, in a series of parallel fire boxes, the heat and products of combustion pass through the length of the flues to stacks at the opposite end. The temperature thus varies in the different parts of the floor. The green molded brick are dumped on this floor and placed usually on edge. The moisture is evaporated and escapes through the ventilators in the roof.

The rapidity of drying is greater than in the open yard or pallet system, and does not depend on weather conditions, so it can be used in bad weather and in the winter. On the other hand, the method is wasteful of heat, and therefore of fuel, and is expensive. The edge of the brick is against the highly heated floor while the upper portion is exposed to the cooler air, and the brick is unevenly heated. In tender clays, these conditions would injure the product, causing the brick to warp and crack.

Some yards equipped with the pallet system have the dry floor as an accessory drier, to be used in inclement weather and during the winter. With gas fuel this method was found in one plant to cost thirty-three cents a 1,000 brick for drying. Fire brick, on account of their porous structure and refractory nature of the clay will not be seriously affected by the uneven temperatures, and the brick are usually dried by this method.

The wood floors, composed of open slats, made in a series of two or three, one above the other, heated by steam pipes along the walls or just below the floor, are in common use for drying sewer pipe, but they are not often used for brick.

In the Kingwood brick plant, steam pipes are laid along the dirt floor in a frame shed, and the green brick are placed on edge across the pipes. This method is rather expensive through loss of brick on account of the high temperature of the edge of the brick on the steam pipe. In some plants, the brick are placed on the floor, with the steam pipes along the sides of the room.

INTERMITTENT TUNNEL DRIERS.

A series of parallel tunnels is built which are separated from each other by partition walls of brick, and each supplied with its own heat and draft. The cars of green brick pass into the tunnel on a steel track, and when filled the doors are closed, the heat turned on and the draft properly regulated until the brick are dry, when the whole tunnel is unloaded. The tunnel is then cooled down to the proper temperature and a new charge added.

There are usually several tunnels, so that while one is being emptied another is in process of drying, and a third may be loaded. The fresh supply of air, often heated by steam pipes below the floor, is admitted by flues in the floor, and the moist air escapes through stacks placed at intervals along the tunnel or from a central chimney.

There is always involved a considerable waste of heat, as the air passes out before it is saturated, and in removing the dried brick the air of the tunnel must be cooled down before a new charge is added, or the brick are apt to crack if subjected suddenly to the high temperature. This intermittent action of the drier limits the daily capacity, but the method has the advantage of giving a complete control over the temperature used in drying, more or less heat may be used, the air circulation may be decreased or increased by the use of dampers. Clays which are very easily cracked during the process of air shrinkage may be handled by this system with greater safety than in other types of driers.

The intermittent tunnel, or chamber drier, as constructed in a number of plants in the State, has the outside walls eight inches thick and the partition walls made with one row of brick or four inches thick. The roof in some types is made of boards, with a layer of earth eight to twelve inches thick to keep in the heat, and the whole protected by a shed roof.

In the floor are the steam pipes, and the air is admitted near, and heat rises around the brick, absorbing the moisture, and escapes through the vapor stacks, which are controlled by dampers so as to regulate the air circulation in the tunnel. The steam pipes are one inch in diameter, and run the length of the tunnel, and a valve at each tunnel serves to control its temperature without interfering with the others.

PROGRESSIVE TUNNEL DRIERS.

In most of the larger brick works and in the more modern small plants, the brick are dried in tunnels like the preceding type, or more commonly in progressive tunnel driers, which are in continuous operation. The tunnels are 80 to 120 feet long, about five feet high and four or five feet wide, with tracks on the floor and connected by tracks with the molding room. A series of tunnels is made side by side under one roof, and provided with partition walls in some types, and without, in others. The tunnels are heated by hot air or steam.

Soft mud bricks are placed on pallets, and these piled one above the other on frames on the steel cars, holding 300 to 400 brick each. Stiff mud brick are stacked on each other on a car, the rows at right angles to each other. For larger capacity, a double deck car is used, each car holding 300 to 625 brick, according to the character of the clay and the kind of car. Figure 13 shows the double deck car of the Standard Dry Kiln Co. The car of green brick is pushed from the molding room to the turn-

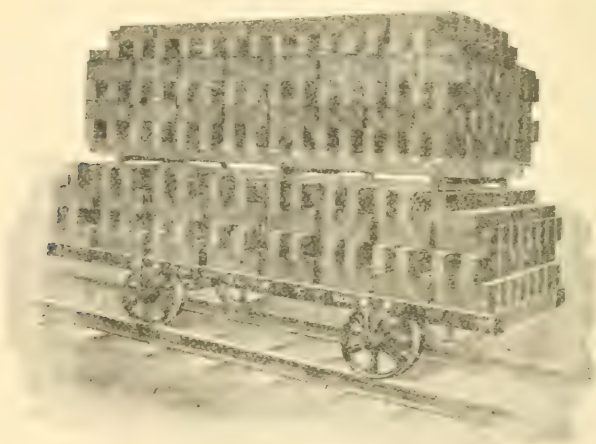


Fig. 13.—Standard Double Deck Brick Car.

table at the tunnel and there turned to the proper track and placed in the cooler end of the tunnel. The next car pushed in back of the first crowds it forward, and so on until the tunnel is filled, the car gradually being pushed to hotter and hotter portions

of the tunnel, finally reaching the discharge end, where the temperature is highest and the drying is completed. By using a number of tunnels for the day's run, the time for the car to pass from one end of the tunnel to the other can be prolonged so that the brick will be very gradually heated and dried, avoiding danger of injury to the brick.

The heat for the drier may be supplied by a furnace, and the heated air is forced into the tunnels by a fan or conducted by pipes. In the Sharer drier, the furnaces are built under the discharge end of the tunnels, and the heat passes by flues under the tracks, the waste gases and moist air escaping through a stack at the entrance end. On each side of the fire boxes are flues to admit air into the drying tunnels. This is heated by the furnace, and rises around the brick. Heat is also radiated from the brick work in the tunnels. The system thus represents a modification of the drying floor, with the elimination of its bad features of over-heating one side of the brick and waste of fuel.

In some plants the heat is drawn by fans, from the cooling kilns through underground flues, and then forced into the tunnels. A mixing chamber, connected with the fans, is arranged to permit fresh air to be drawn in, and so reduce the temperature of the kiln gases if these are too hot. By changing the speed of the fan, the amount of air blown into the tunnels is regulated. This method has proved very satisfactory in not only furnishing cheap heat, which would otherwise go to waste, but in reducing the time required to cool the kilns. It is claimed that with a good arrangement of flues and fan, the kilns are cooled in one-half the usual time.

When this method is adopted, an auxiliary furnace equipped with heater coils is usually provided to furnish heat for the drier when there is not enough available heat from the kilns or in case of break-down in the system of flues. The fan draws the heated gases through a long flue or tunnel which runs underground along the front of the kilns, with branching tunnels to each kiln controlled by an iron damper, which can be raised, giving connection with the kiln or lowered, closing the connection with the kiln.

The steam tunnel driers have a variety of arrangements of steam coils and draft regulating devices. One of the popular

types in this State is the Standard drier, made in Indianapolis, and shown in sectional drawing in Figure 14. At the discharging end of the drier is a series of radiator coils which are connected with steam pipes along the floor between the tracks and along the walls of each tunnel. At the receiving end, the air is warm and moist, so that the car of green brick here comes into a moist

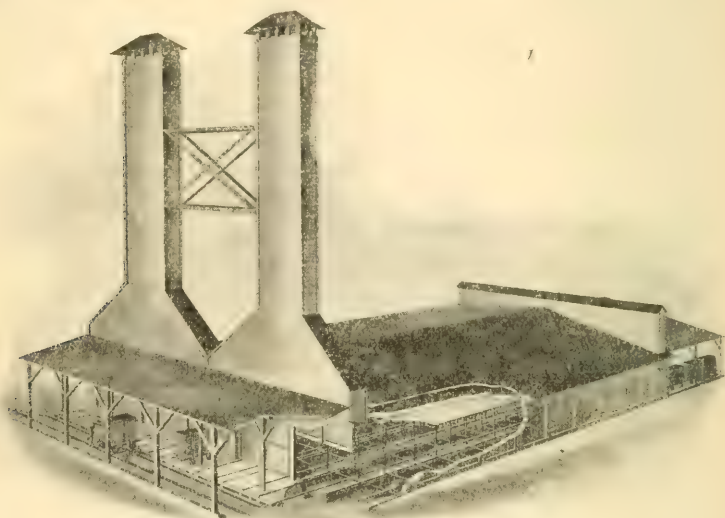


Fig. 14.—Standard Ten Track Tunnel Brick Drier.

atmosphere heated, and the brick are raised in temperature without drying and shrinking. As other cars are added, the brick are pushed forward into an atmosphere containing less moisture and more heat, so that they begin to dry and shrink.

As the cars are worked toward the exit end and toward the steam coil radiators, the air is drier, and the heat greater, reaching their maximum at the discharge end, where practically all the moisture is removed from the brick, and air shrinkage is at an end.

In all these methods the process is continuous and progressive. The tunnel is filled and the new car of green brick crowds out the first car with its brick ready for the kiln. The tracks are constructed so the cars of dry brick can be taken to the kilns and over temporary tracks into the kiln, where they are unloaded. During the day in the steam tunnels exhaust steam

from the boilers is used, and at night, when the brick presses are stopped, live steam is connected with the tunnels.

It requires for average brick about twenty-four hours for the car of brick to go through the tunnel, and in very slow drying brick the time required may reach forty-eight hours. The steam tunnel driers are in common use in this State, and the temperature at the receiving end is about 100° F., and at the discharge end may run over 212°.

The driers are composed of tunnels with one to four tracks in each tunnel. One track holds 15 to 110 cars, according to the length of the tunnel, and the total capacity in the plants of this State ranges from 40,000 to 220,000 brick.

BURNING OF BRICK IN KILNS.

After the brick are thoroughly dried they are removed to the kiln on carts from the open yard or dry floor, or on the steel cars from the tunnel driers, and are stacked for burning. The fuel used is wood, coke, coal, oil, or gas.

The water added in tempering the clay is removed by the driers, but there remains a small percentage of hygroscopic moisture which, if removed in drying, will be taken up again as soon as the brick are exposed to the air. There is also present the water of chemical combination, four to eight per cent. in average brick clays, which is removed at about the temperature of 1000° F., or red heat.

The following description of the changes in the clay product in burning is based on a report of Prof. Edward Orton, Jr.,¹ and the valuable suggestions in this article are bound to be of interest and service to the brick operators in this State, so that it has seemed advisable to quote freely from the article mentioned, and the writer wishes to give due credit for the facts and suggestions herein stated.

The burning of brick in the kiln has been divided by Orton into three divisions, which to some extent overlap, but correspond to the important reactions at different temperatures:

1. On the Role Played by Iron in the Burning of Clays, by Edward Orton, Jr., in *Brick*, Vol. XX., No. 1, p. 31, 1904, being a reprint from Vol. V., *Transactions of American Ceramic Society*.

1. *Dehydration Period*.—The dissociation of materials which are unstable at high temperatures, and the expulsion of the volatile portions from the mass of the clay.

2. *Oxidation Period*.—The transformation of the non-volatile elements from less stable into more stable forms by absorption of gases from without the mass.

3. *Vitrification Period*.—The amalgamation at an elevated temperature of the various residual inorganic substances left by the two preceding reactions, into a more or less perfect silicate compound.

Dehydration Period.

During the first period the hygroscopic water is eliminated, which completes the removal of moisture from brick, there remaining the water of chemical combination in the kaolin and other hydrous minerals of the clay. As long as moisture remains in the clay, it is difficult to raise the temperature to produce the necessary reactions in burning the ware. It thus becomes important to have the brick delivered to the kiln with all the moisture possible removed by the drier, or there will be a waste of fuel in drying the kiln.

The free water is removed near the boiling point, and if the kiln is heated too rapidly the water in the brick will be changed to steam, cracking the brick, or if the draft is poor, the moisture will be condensed on the brick in cooler portions of the kiln. In the preliminary heating of the kiln, the hygroscopic moisture and any water of plasticity remaining through incomplete drying are removed. In this period termed "water smoking," it is essential that the temperature be only gradually raised, and that a good circulation of air be present.

The sulphur of the fuel is apt to unite with the water, forming an acid, and if this condenses on the surface of brick containing soluble impurities, these may be dissolved, and as the acid moisture evaporates will leave a coating or wash, disfiguring the brick. Such a trouble, due to this cause, is to be prevented by good draft, with its resulting good air circulation, which will prevent the condensation of moisture, and its removal through the top of the kiln or through the vapor stacks. In some cases the salts formed may remain hidden in the structure of the brick, to

be brought to the surface by absorbed moisture after the brick are placed in the wall.

During the hydration period the vegetable matter in the clay is mainly removed, and if present in any quantity will by its combustion add to the temperature of the kiln. The rootlets, leaves and bits of wood readily burn out during this period, and will usually cause little or no trouble; but in many shales and some clays there is a considerable percentage of partially altered vegetable matter which is not much changed at low temperatures, but under increased heat breaks up into combustible gas and leaves a residue of coke. The burning gas may thus increase the temperature at a time when it should be kept down to permit oxidation, or it may even cause a fusion of clays of low fusibility, producing melted and misshapen brick. The presence of this form of organic matter at these temperatures is very apt to cause a reduction of the iron and to prevent the oxidation of the ferrous iron, giving the brick a dark black color.

At the close of the dehydration period the ware is porous through the loss of water, of carbonic acid from the carbonates, and loss of organic matter. There has been little or no fusion of the particles in the clay, fire shrinkage has not commenced, the hardness is very little higher than that of the dried clay, and the color if iron is present is a pale red. Brick removed from the kiln at this point would be useless.

Oxidation Period.

In the second, or oxidation period, the temperature of the kiln is raised, oxygen unites with the simple iron oxide (FeO) or with the sulphide (FeS_2) and forms ferric oxide (Fe_2O_3). The sulphide of iron in this period loses one of its molecules of sulphur, while the other is only removed at very high temperatures. The ferric oxide must be formed to give a good red color to the brick. This period in brick burning is one of the very important stages, and its importance is sometimes overlooked by the brick worker, with a result of poor brick. The clay must be well oxidized to insure a successful kiln of brick.

Under ordinary conditions, this oxidation of iron is a common and easy process, taking place all around us in the ordinary reactions of nature; but in the clay molded into brick and set in a

kiln, there are several reasons why the reaction may be hindered or even prevented.

The iron is distributed through a compressed clay among a mass of fine grained particles, which form a barrier to the outside air. This air, with its oxygen content, must penetrate the fine capillary tube system of the clay to reach these iron particles, and this operation requires time.

The carbonates of lime, magnesia, or iron, have lost a part of their carbonic acid, but not all of it, which now, under added temperature, escapes, and passing out these fine tubes and pores prevents for a time the entrance of the air with its oxygen.

The kiln atmosphere does not consist of pure air rich in oxygen, but of air contaminated with the gases of combustion and escaping gases from the clay, so the circulation of gases through the kiln must be increased, and more fuel must be added to insure a good circulation in all parts of the kiln. Most of these waste gases are reducing in their action, that is, they remove oxygen rather than supply it to the clay particles. It requires time to overcome this reducing effect, and for the kiln atmosphere to become oxidizing through a surplus of oxygen. A greater supply of fresh air might be admitted through the air holes, but this would lower the temperature of the kiln at a time when the temperature must be elevated. The draft must be very carefully regulated, so as to admit sufficient air to render the kiln atmosphere oxidizing, but this must be done without lowering the temperature, a delicate adjustment which can only be accomplished in a sufficient time interval.

The iron sulphide has a stronger affinity for oxygen than the iron oxide (FeO), so the former must be oxidized before oxidation of the latter begins. If the clay is very fine grained, the oxidation will be even slower. There is also a difference due to the way the brick have been made. According to Orton, an end cut brick made from some clays oxidizes more slowly than a side cut, on account of the direction of the planes of lamination in the brick, which in the end cut protects the center by sheath over sheath, covered with a smooth, compact surface film of clay, while in the side cut brick the center is made accessible by the lamination planes leading into it and also by the roughened surface.

At the end of the oxidation period, if successful, the brick will have a uniform color from surface to the center, there will be

no cores of different shade. The brick will be some harder than before, and shrinkage has commenced, but as yet the percentage is low. The brick is not at this point a salable product.

If the color does not reach the center, oxidation is incomplete, and the ware will be injured in the later firing. If the brick are piled closely and the air circulation has varied in different places, the oxidation is incomplete, and varied colors are found. This variation is more marked when organic matter is present during the process of oxidation. In one kiln in a certain plant in this State, about ten distinct shades of color were found, buff, light and dark red, salmon, black, various shades of brown, and a very considerable number of transitional shades. It would have been difficult to select any quantity of brick of the same color from this kiln. It was burned for red building brick, and for this purpose it represented a failure. Another kiln nearby, made from the same clay and by the same process and with the same kind of fuel, showed a good red brick. The brick burner could give no reason for the failure.

Vitrification Period.

The third, or vitrification, period, begins about 900° C., and while the exact nature of the changes in this period is not well understood, certain results are known to occur. The stages of fusion of a clay have been given in Chapter III. as condensation, incipient fusion, vitrification, and viscosity or fusion.

In the preliminary stages of vitrification in the condensation period, there is probably a shrinkage of the kaolin base, then the basic oxides of lime and magnesia acting on the dehydrated clay form silicates and aluminates, the other elements of the clay become involved in the reaction, and compound after compound is formed.

When heated to still higher temperatures some of these compounds fuse and cement together the remaining particles, the fusion increasing in amount with the increase in temperature until the mass begins to soften and flow, forming a glass, and vitrification is completed. There will still remain unfused particles imbedded in the glassy matrix, and the result is a clay glass or slag. In this process the clay product becomes denser and stronger, reaching a maximum at a certain temperature, varying with the nature of the clay, and then begins to fall until there

results the brittle, often vesicular, useless slag. This is, therefore, another important stage in burning, for the kiln operator must bring a kiln of paving brick as near this maximum as possible, and not carry the temperature over to the viscous stage.

Ordinary building brick are usually brought to the stage of incipient fusion, that is, carried through the condensation period, which is the preliminary stage of vitrification.

As the iron bearing clay is heated, the iron color becomes deeper and reaches its maximum at about 1100° C. As the temperature is increased beyond the point of maximum redness in the brick, the color usually darkens as the iron combines with silica, and forms ferrous silicate dark in color.

If the kiln atmosphere is reducing from smoky fires or poor air supply, the color becomes greenish or bluish black. If the iron is present in small concretionary grains it may cause blisters on the surface of the ware, due to a change to the ferrous oxide, which unites with silica and fuses to a stiff viscous mass with enclosed gases, which form small bubbles or blotches on the ware. If the temperature is carried higher these viscous masses will melt and form black smooth spots on the surface, as seen on some paving blocks. These results are to be avoided by keeping the kiln atmosphere oxidizing through using a good draft, non-smoking fire, thus removing the reducing action with its formation of ferrous oxide, which in turn forms with silica the ferrous silicate.

If the clay has not been sufficiently oxidized in the oxidation period of burning, this process will never be completed, according to Orton, for two reasons: First, because the porosity of the ware rapidly diminishes as the temperature rises, so that at a temperature of 900° C., the porosity of most clays is so reduced that the oxygen cannot penetrate its different parts, and oxidation is at an end; second, in order to secure the increase in temperature essential for the vitrification stage of burning, it becomes necessary to cut down the amount of free air admitted to the kiln, with the result that the gases become reducing or nearly neutral at a temperature of about 1200° C. With gas fuel the temperature may be raised to 1300° C. before this result is reached.

In the clay not completely oxidized, the silicate combination takes place at a lower temperature, and so lowers the point of melting, increasing the danger of over-burning. There also

results an evolution of gases which will give the ware a spongy or slag-like character. The amount of this gas evolution, according to Orton, depends on: 1. The amount of material in the original clay which is capable of producing gas, that is, the amount of carbon, carbonates and sulphides; 2. The completeness with which these substances have been burned out from the clay while it was still porous; 3. The amount of overheating after the gases begin to come off.

The black ferrous portion of the ware will be expanded by the gas, and may thus crowd the ware out of shape, but even if the shape is retained, the product will be less strong, and a small quantity of the gases is sufficient to make the ware very brittle.

By subjecting the ware to alternate oxidizing and reducing conditions, the surface color may be changed. By repeating the action, the color becomes more brilliant. This process is termed *flashing*, and it may occur through accidental causes or by purposely changing the draft so as to produce certain colors in the brick. Buff burning clays may in this way yield golden, or brown shades. Red burning clays may give a chocolate, or nearly black, shade.

If the clay is heated beyond the point of complete vitrification to that of viscous flow, it is fused, and can no longer withstand the pressure of the overlying layers in the kiln. It will be pressed out of shape and become vesicular through the escape of gases formed by the decomposition of any sulphates remaining at these high temperatures. The color then becomes black as the ferric oxide breaks down, forming ferrous oxide, which unites with the silica to form ferrous silicate.

From the foregoing facts and explanations it is readily seen that the burning of a kiln of clay products is not a simple operation, to be performed by unskilled persons. The successful kiln burner must understand the nature of his clay and the changes which take place in its burning. He must be prepared to control the fires and drafts to insure complete oxidation before increasing the kiln temperature for vitrification. He must know how to bring the ware to the correct temperature where vitrification will take place with the maximum strength of product, and not carry it too far, where the ware will be softened and lose its shape and strength.

The more closely the burner approaches this correct temperature and maintains it until the process is complete, the better will be the product in strength, low absorption of water, and wearing properties. Especially is this true in the manufacture of paving brick, where these qualities determine the life of the pavement. He can accomplish these results better in the down-draft type of kiln than in the up-draft, because he has a better control over the temperature and the supply of air. This type of kiln is used for vitrified wares which require temperatures from 1800° to 2200° F.

In the manufacture of building brick, the kiln is only raised to the temperature of incipient fusion about 900° to 1200° C., as the very high temperatures are not required, and either type of kiln may be used.

TYPES OF KILNS.

There is a considerable variety of kilns in use for burning brick, which may be grouped in two classes, *up-draft* and *down-draft*, the latter made circular or rectangular in shape. In the up-draft kiln the heat passes from below upward and out at the top of the kiln, bringing the highest temperature near the bottom. In the down-draft kilns the heat passes through vertical flues or chimneys to the top of the kiln and passes out through flues at the bottom the kiln, bringing the highest temperature near the top of the kiln. Both types are used for building brick and the second type is used for vitrified products.

UP-DRAFT KILNS.

One of the simplest types of kilns is the up-draft scove kiln, used in a number of the small hand mold brick yards. In this type the brick are stacked for burning and the kiln walls built around the unburned brick. These walls are made of old brick from the yard, and built ten to twelve inches thick. The temporary walls are daubed over with mud, or *scored*, as it is termed, to make the walls as nearly air-tight as possible. When the kiln is burned and cooled these walls are taken down and built anew with the next kiln.

The brick are set in arches widening below and extending across the kiln, forming the fire box. The arch is twelve to fourteen courses high, about twenty inches wide, and two feet between arches. The number of arches in these kilns in this State runs

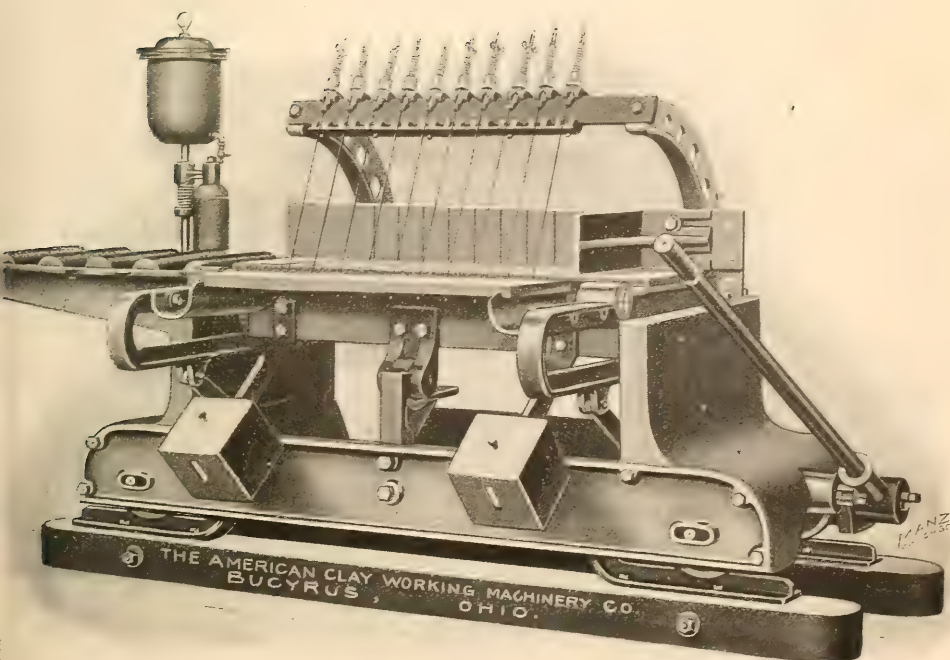
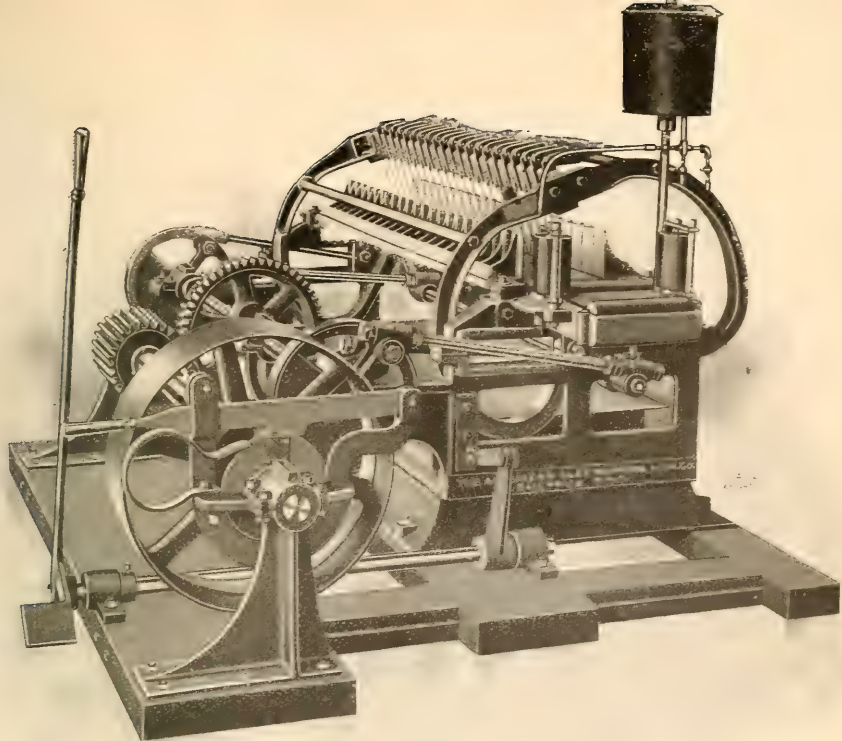


Plate IX.—American Down Cut Brick Delivery Tables.

from nine to fifteen. Across the top of the arches two or three courses of brick are laid, forming the tie course. The brick are then set three on three, each course being at right angles to the one below, and so set as to leave openings between the brick for circulation of the heat and air, and about thirty courses high. The top is covered with burned brick in two or three courses, called the *plating*. A shed roof, set on poles, protects the kiln, and is extended out on both sides to protect the workmen to some extent from the weather.

In burning the kiln, every other brick of the *plating* is turned so as to open the draft, and a light fire is started in the outer portion of the arches on both sides and gradually increased until they meet at the center. During this period, the brick are thoroughly dried, and the vapor passes out of the open top, so it is called the period of *water smoking*. Wood is the popular fuel for this purpose, and is used whenever it can be obtained at a moderate price. The low fires are maintained from two to three days, and the fire is increased until it reaches the top, when the *plating* courses are turned flat and the heat continued for four to six days until the brick are sufficiently burned. Where gas fuel is used, the pressure is regulated so as to give a low heat during the water smoking period, or in some places wood is used, and in one plant coke was used, with gas for the final burning. After the kiln is burned, the fire openings of the arches are walled up with brick and mud and the kiln left to cool five to seven days.

The brick in the arches are hard burned, and often melt sticking together, and their exposed ends colored black from the carbon of the fuel. The ends are sometimes yellow streaked or tinged by the sulphur in the coal. The middle courses are burned to a good color, while the upper courses are soft burned, forming the salmon brick.

These kilns are cheap in construction, and can be erected by the yard laborers. There is involved a very considerable waste of heat through the thin walls and a loss of brick through lack of sufficient heat in portions of the kiln, and too much heat in other parts.

PERMANENT UP-DRAFT KILNS.

If the brick yard is to be operated on any extensive scale, the up-draft kilns are made in permanent form. In new plants it

is often desirable to build temporary wall kilns for several burnings until the ground is thoroughly dried and in good condition for the permanent walls.

In the permanent kilns, the side walls, usually one end wall and a portion of the other end wall are built of good brick set in mortar. The walls are about thirty inches thick at the bottom, and while vertical on the inside, they taper to about one foot thick at the top.

The brick are stacked in the kiln in the same way as in the temporary kilns. The side walls are built up six or eight courses higher with loose brick and the top is covered with the platting courses. The arches connect with fire hole openings in the side walls, and after the kiln is filled the ends are closed with loose brick and plastered with mud. Plate XII. shows one of these kilns with the end wall removed and the brick ready to be taken out.

When wood fuel is used the fire places are similar to those in the scove kilns. If coal is used the grate bars are added, which may be placed only in the entrance to the arch or in some types pass clear across the kiln. The entrance is controlled by an iron door. Openings are left in the wall to admit air and are closed when necessary by a brick with mud placed around it.

In the Morrison type of kilns the lower portion of the wall is built out to form furnaces in which the fuel is consumed, one furnace giving the heat for three arches. This method is claimed to give better control over the temperature of the kiln and also to use less fuel.

A large number of the plants in West Virginia use gas fuel, which is burned in these furnaces or in the fire holes in the walls of the kiln. The gas burners are provided with adjustable mixers so the flame can be made reducing (yellow) or oxidizing (blue).

In the up-draft kilns the lower portion of arch brick is over burned and more or less melted together, the brick in settling at this point throw considerable weight of overlying brick against the kilns walls and in time push these outward. To overcome this trouble they are supported by iron band clamps, or by building at intervals heavy pier supporting walls.

In a number of kilns in the eastern part of the state small piers two feet square and thirty inches high are built of brick at

the sides of the fire places, and the arches rest on these, which arrangement brings the unburned brick above the level of the fire. This avoids to a large extent the settling and crowding of the brick against the outer wall, giving greater length of service to the kiln before it is necessary to rebuild the walls. There is in this method no real loss of room, for the brick at the place of the piers would be ruined by the great heat.

The up-draft permanent kilns are in common use in the state for burning building brick. The brick are placed in the kilns thirty-two to forty-two courses high, and the kilns are made with nine to twenty-four arches, holding 140,000 to 400,000 brick, which are burned in seven or eight days and cooled in six to eight days.

DOWN DRAFT KILNS.

Down draft kilns are made in circular or rectangular form and with one or several stacks to each kiln, and also with one stack to two to four kilns. The fire places lead into enclosed apartments or muffles which are open near the top of the kiln, the heat thus passes to the top of the kiln and is drawn down into flues in the floor which lead into a flue to the stack. The different types of these kilns vary in the construction of the fire places, the number of stacks and the arrangement of the floor flues.

In the older down-draft kilns there is one stack to each kiln, or in a few types two stacks, one opposite the other. In the later kilns built in this State there is one stack to two to four kilns. The stack is divided into compartments giving three flues part or all the way to the top of the stack. Dampers serve to open or close the connection of any kiln with the stack. The rectangular kilns often have several stacks built in the wall, but in some types there is one stack at the end, or two kilns drawing into one stack.

The flues in the floor are arranged to give a draft to the stack and thus draw the heat down through the brick. In the older types there was a single stack to the kiln and connected with a central open well in the kiln by an open flue; or with two opposite stacks the flues passed across the kiln opening into the stacks. In this arrangement the heat would pass to the stacks over the shortest path, thus over burning the brick around the stack and under burning the other parts of the kiln.

A modification of this type consisted in running a covered flue from the center of the kiln to the stack and an open flue at right angles across the kiln at the center. The piers supporting the kiln floor were built in open checkerwork to permit the heat to reach all portions of the floor. This resulted in a good supply of heat at the center and near the cross flue, but not around the circumference of the kiln.

In another modification concentric flues were made in the floor of the kiln and an open flue leading from the stack to the center cut these circular flues, but in this type the greatest heat was toward the stack.

EXTRACTS FROM PIPE KILN REPORTS FOR THE YEARS
1903 AND 1904.

Kiln No.	Size.	Average tons of pipe set in kiln.	Average tons of coal to burn kiln.	Average tons of coal to one ton of pipe.	Temper- ature burnt off.	Time burn- ing.
I.	35' diameter.	111.15	34.5	.34	2300°	10 days.
II.	38' "	134.18	43.15	.321	to	10 "
III.	35' "	112.85	33.0	.294	2400°	9 "
IV.	30' "	72.11	31.94	.442		9 "
V.	35'x31'	88.44	31.63	.356		9 "
VI.	27'x21'	38.83	22.58	.581		6 "
VII.	30'x25'	52.6	26.8	.509		9 "
VIII.	30'x25'	70.0	25.47	.426		8 "
IX.	21'	40.26	19.03	.473		5 "
X.	35'	112.38	34.67	.308		10 "
XI.	21'	39.18	19.41	.496		5 "
XII.	27'x22'	42.69	21.47	.503		7 "
XIII.	28'x18'8"	51.35	28.06	.444		7 "
XIV.	25'	41.55	20.23	.487		5 "
XV.	35'	106.57	33.74	.316		10 "
XVI.	30'	64.44	29.31	.406		9 "
XVII.	35'	106.24	32.14	.324		10 "
XVIII.	30'	60.87	28.22	.465		7 "
XIX.	30'	80.39	25.85	.321		8 "
XX.	25'	43.56	20.61	.473		7 "

In some kilns there is a central well partly covered and connected with the stack by a covered flue. From the central well radiate a number of covered flues which lead into a circular open flue around the circumference, the radial flues coming between the fire place muffles. This method brings the heat to the circumference, and from there the heat travels to the center of the kiln. With a good arrangement of the brick in the kiln this method yields good results in burning. The floor of the kiln is usually a

false floor made of fire brick supported by brick piers below and set in a checker work to permit free movement of the gases.

The circular down draft kilns in this State are made 26 to 30 feet in diameter. The 28-foot kiln holds about 65,000 standard size brick or 35,000 paving blocks, and the larger size about 80,000 standard brick. The down draft kilns at the Mack Company yards at New Cumberland are shown in the upper part of plate XIII.

The larger size kilns are more economical in fuel in proportion to the amount of product made. An interesting series of observations has been made on this subject by the Evens & Howard Fire Brick Company at their St. Louis plant, which shows that the larger kilns use less fuel per unit of finished product than the smaller types. The foregoing table of these observations has been kindly furnished by the general manager of this company, W. J. Hemphill:

CONTINUOUS KILNS.

The earliest type of continuous kiln is the Hoffman kiln, first constructed in Germany and used in a number of brick plants in that country. The various types of continuous kilns have several apartments connected with each other and with a central stack. The different parts of the kiln are filled with brick and the fires started in one division, and after the water smoking period, its connection with the stack is closed and the heated gases pass through openings to the adjoining parts of the kiln, drying and raising the temperature of the brick. Fuel is introduced into the compartments of the kiln through openings in the roof.

While brick are drying in one part other parts are being burned, and others are cooling. When one division is burned and the brick cooled, they are removed and the division filled with green brick. The continuous kiln is only used to a limited extent in this country. In West Virginia one continuous kiln was built at New Cumberland, and while it proved fairly successful for building brick, it was a failure for paving brick and it has not been used for some years.

CHAPTER VI.

TECHNOLOGY OF THE CLAY INDUSTRIES—POTTERY AND SEWER PIPE.

POTTERY.

From the dawn of civilization, the art of molding clay into vessels for the use of man has been known, starting with the early primitive types and gradually evolving into the beautiful art pottery of more modern times.

Pottery was made by the early settlers in Virginia and in New York in 1640, and while much progress was made from that time to 1876, the American pottery industry received its first great impetus through the Centennial Exposition in 1876.¹

West Virginia ranks fifth² in pottery products, being surpassed by Ohio, New Jersey, Pennsylvania and New York. Nearly one-half of the total value of clay products of this State is represented by the output of the potteries. The decorated ware made in West Virginia in 1904 amounted to \$573,187, the plain white semi-vitreous porcelain had a value of \$339,754; stoneware, \$18,923, and miscellaneous articles including sanitary ware, \$184,259, or a total of \$1,116,117 out of \$2,074,549 for all the clay industries of the State.

KINDS OF POTTERY.

The grades of pottery manufactured in this country may be grouped under the following heads:

1. Earthenware.
2. Stoneware.
3. Yellow and Rockingham ware.
4. C. C. ware.
5. White granite or ironstone china.
6. China or porcelain.

1. Ries in U. S. Geol. Survey, 17th Annual, Part III, p. 842.

2. Statistics in this chapter from U. S. Geol. Survey.

7. Ornamental pottery, including belleek, delft, majolica, lustre ware.

1. **Earthenware** includes the clay vessels burned hard without vitrification. They are soft and porous and cannot be used for holding liquids. Examples of this class of ware are flower pots, flower vases, pedestals, umbrella stands, etc. They are usually made in red color, more rarely buff, and may be made plain or ornamental with dull colors. These products are made from rather low grade plastic clay, and are made at the present time in this State at two places on a small scale.

2. **Stoneware** is usually more or less vitrified, requiring higher temperatures than the earthenware. The burning and glazing are accomplished in one operation. The glaze applied is either salt or a slip clay. The salt glazed ware is usually gray in color, while the slip glazed ware is usually red or brown but sometimes white. The salt glazed ware often has a slip glaze on the interior. Useful stoneware products are fruit jars, jugs, crocks, churns, pitchers, water filters, etc. Stoneware cooking utensils are now made which can be set directly over the fire.

3. **Yellow and Rockingham Ware** have the clay body burned to a hard porous body in the kiln, and then covered with a lead glaze and fired a second time. Rockingham ware is colored brown with manganese, while in the yellow ware the glaze is transparent so that the buff color of the natural clay shows through with the added lustre of the glaze. The ware is burned in saggars made of fire clay. The articles made in this grade of ware are bowls, pitchers, tea pots, baking dishes, jugs, mugs, stew pans, soap dishes, etc. This industry has been on a decline for the past few years but in 1903 showed a gain of 33.26 per cent. over 1902, and was made that year by seventeen firms in this country. In 1904 there was a little loss in production over 1903.

4. **C. C. Ware** or cream colored ware is made from a mixture of kaolin, ball clay, flint, and feldspar. The materials used are of lower grade and more impure than those used for white china. The iron of the clays is not counteracted by chemicals, so that a slight yellowish tinge is given the ware, which is often concealed by a heavy glaze. This cheaper ware with its defects hidden by a glaze may have a close resemblance to higher grades

of china, though in time the defective color may appear through the glaze. The varieties of C. C. ware are similar to those made in the white china. Twenty firms were engaged in manufacture of this ware in 1903, as compared with twenty-three in 1902, but the number decreased in 1904 to twelve.

5. **White Granite or Ironstone China** is made from the same kind of mixture as the C. C. ware, but purer materials are used and the iron present is counteracted by the use of cobalt which gives a slight greenish tinge hardly noticed in a single piece. Both this grade of ware and the C. C. are burned in biscuit kilns to a hard porous body which is then dipped into a glaze made of borax, boracic acid, feldspar, whiting, and white lead made into a liquid slip, and burned a second time.

The ware is only partially vitrified, rendered opaque and hard so as to withstand rough usage. The ironstone china is a harder and heavier grade than the white granite or semi-vitreous porcelain, but these terms are often used as synonyms. The ware commonly bears on the under surface the trade mark and name of the pottery. The articles made are table, cooking, and toilet ware, and ornaments. The ware may be ornamented by bands of gold or enamels, or by print designs.

A special variety of white granite ware is the sanitary ware, vitrified so as to be non-absorbing. The wash bowls and toilet bowls are molded in several pieces joined together before burning. Bath tubs are molded in sectional molds and the glaze applied to the interior with a brush. These large pieces of sanitary ware must be dried slowly for several weeks, and burned slowly in muffle kilns.

Another important branch of this industry is the manufacture of electrical supplies, as fuse boxes, insulators, insulator tubes for wires, etc. They are made with a vitreous body which is then glazed. The pottery at New Cumberland is the only one in the State engaged in this line of manufacture.

6. **China or Porcelain** is made from the same kind of materials as the preceding two groups, but great care is taken in the selection of the finest and purest materials, which are finely ground, mixed, and thoroughly fused. This grade transmits light, becoming translucent. The thinner varieties of china are called porcelain, though in this country there is a tendency in certain

sections to apply the term porcelain to the seim-vitreous white granite. The well known grades of china in this country are the Sevres, Limoges, and Dresden imported, but fine grades of china are made at a number of places in the United States.

7. Ornamental Pottery. Belleek ware or egg shell china is very thin and delicate. It has a cream enamel surface, or may be covered with a transparent glaze.

Delft ware has a body of white china, covered with blue designs originally representing Dutch scenery, and was made at Delft, Holland. It is now made in this country in form of plates, trays, vases, clocks, etc.

Majolica is an earthenware decorated in many colors which are applied to the ware in the glaze. The ware is burned at a low temperature and impure clays are often used as the defects are hidden under the bright colors used. Lustre ware has a glaze of metallic oxides which gives the articles a metallic appearance often with a marked play of colors.

POTTERY CLAYS.

The kinds of clay used for pottery manufacture have been discussed in Chapter IV. The mixture for the higher grades of pottery includes china clays, plastic ball clays, feldspar, and quartz.

PROCESS OF MANUFACTURE.

Preliminary Treatment.	{ Blungers. Screens. Agitators. Filter Presses.
Tempering	{ Pug Mill. Wet Pan. Chaser Mill.
Molding	{ Jolly. Turning Lathe. Casting.
Drying.	
Burning.	
Glazing.	
Decorating.	

PRELIMINARY TREATMENT OF POTTERY CLAYS.

The clay for earthenware and stoneware is usually taken from the bank and tempered without preliminary treatment.

In the higher grades of pottery, the clays are washed in a clay washer or in blunger mills. The former type is a horizontal

wooden box with a steel shaft through the center to which are attached steel teeth or arms which by the revolution of the shaft stir and cut the clay. A current of water passing through removes the fine clay leaving the coarser particles behind to be more thoroughly disintegrated.

In the blunger mill the clay is placed in circular vertical tanks made usually of steel, five or six feet in diameter, filled with water. The mixture is stirred by revolving arms, and consists of about 20 per cent of clay and 80 per cent of water. After

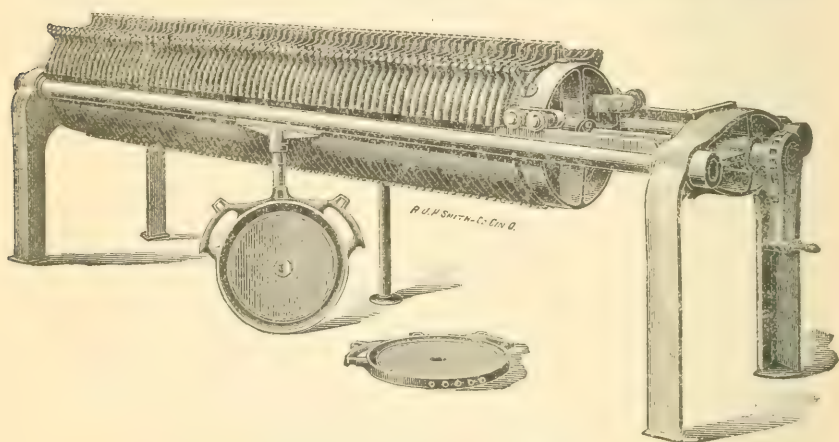


Fig. 15.—Clay Filter Press.

it is thoroughly mixed the mixture is allowed to run out of the tank through a gate near the bottom, passing over coarse screens to the rough agitator in which the clay and water now freed from the coarsest particles are further stirred by revolving arms.

The clay and water are run from the rough agitator over oscillating fine mesh silk lawn screens into the tanks of the smooth agitators below. From these tanks the mixture is drawn through the compound slip pumps and forced into filter presses. One pump is usually connected with two presses, so one may be filling while the clay is removed from the other. The filter press, figure 15, consists of two massive end frames connected by steel side bars and supported by four steel legs. On the side bars are placed the iron or steel plates perforated at the center with a one or two-inch hole for the clay and water mixture to pass through. Between the plates are fastened the single or double sheets of filtering canvas forming a bag.

The clay and water are forced by the filter pump through the perforated iron plates and the canvas bags under a pressure of 75 to 150 pounds, the water is forced out and the clay forms a plate or cake inside of the canvas bags. When the operation is completed, these plates of clay, 26 to 28 inches in diameter and one and one-fourth inches thick, now containing about 20 per cent of water, are removed and placed in a cellar for a month or more. A common size of press is 16 feet long and holds 72 cakes of clay. Smaller sizes are made with a capacity of 36, 42, 48, or 54 leaves or cakes. The plates of these presses are made square or round, the latter type being more common in this section.

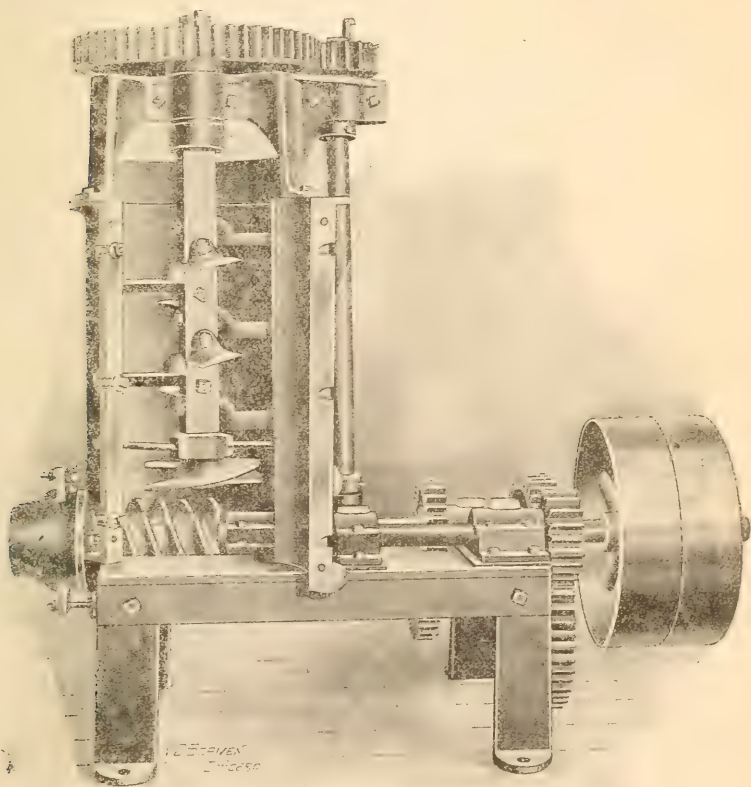


Fig. 16—Potter's Pug Mill.

TEMPERING OF POTTERY CLAYS.

The filtered cakes of clay are tempered in a potter's pug mill which is a vertical cylinder or barrel with a vertical revolving shaft to which are attached cutting knives, and with a horizontal shaft below made in the form of an auger which pushes the tempered clay out through the die in a column. This clay column is cut into small masses placed on an elevator to be carried to the molding or turning room. The pug mill made by the Patterson Foundry Co. is shown in figure 16.

In earthenware and stoneware manufacture the clays are often ground and tempered in one operation in the wet pan described in the preceding chapter, or in chaser mills in which the mullers or rollers are arranged to move back and forth across the width of the pan.

MOLDING OF POTTERY.

The clay is molded on jolly wheels, turning lathes, or it is pressed or cast in the desired form. The clay is brought from the pug mill in small chunks or masses to the potter's table where it is wedged, that is cut into two halves by a wire, the two portions forced sharply together, then cut again and forced together, and so on until the structure becomes firm and air bubbles are removed.

In the manufacture of earthenware and stoneware a lump of wedged clay is placed on the throwing-wheel, shown in figure 17, which is a horizontal circular steel plate revolved rapidly by foot or steam power. The potter skillfully works the clay up in the desired shape with his fingers, and when completed, detaches the ware from the wheel by passing a wire underneath it, and the article is set aside to dry.

The jolly is a wheel with a hollow receptacle in which is placed a plaster of Paris mold whose interior has the shape of the exterior of the article to be molded. A lump of clay is placed in the mold and pressed into shape with the fingers, then the operation is completed by an arm or pull-down which presses the clay firmly in the mold and gives the shape of the interior of the article. The Patterson Foundry Company jolly is shown in plate XIV.

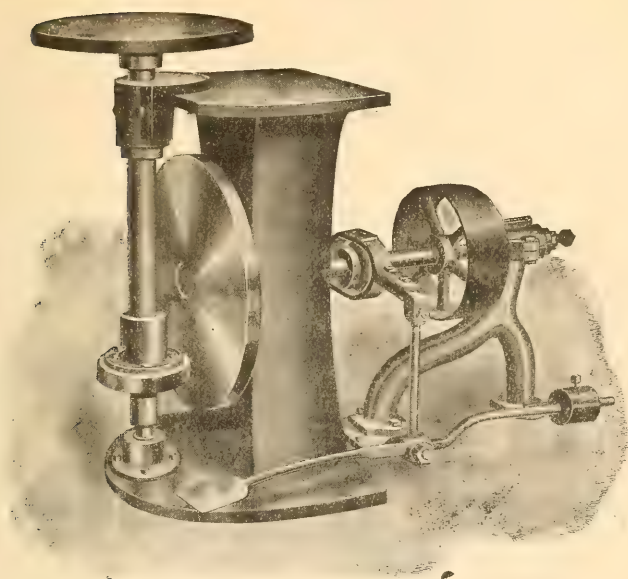


Fig. 17.—Potter's Throw Wheel.

Complicated patterns are molded in sectional molds, the clay is pressed in each section and the sections placed together, the seams being smoothed down with a wet sponge. Handles of jugs and other articles are molded from strips of clay and fastened to the proper place with a clay slip.

In the manufacture of saucers and plates a horizontal lathe is used, the mold fastened to the lathe has the shape of the inside of the articles. A lump of clay is pressed down over the mold while the outer shape is given by the pull-down arm with its edge cut in the proper shape to give the desired form to the ware. Thin porcelain is made by a process of *casting*. The clay is mixed with water to form a slip which is poured into porous molds and leaves a thin layer of clay in the mold. This is repeated and the surplus slip emptied from the mold. After the clay is sufficiently dry it is removed in very thin forms.

DRYING OF POTTERY.

The molded ware is set aside on shelves in racks in enclosed rooms heated by steam or hot air for 20 to 48 hours.

GLAZING AND BURNING OF STONEWARE.

Stoneware is glazed with salt or slip clays. Salt glazing has been in use since 1680, and is in common use for stoneware. Near the end of the burning process common salt (chloride of sodium) is thrown into the fire and the vapor rising through the ware unites with the free silica forming a silicate of sodium glaze which is transparent, giving the ware the characteristic gray color.

Slip clays are clays of low fusibility which are mixed with water to a creamy mass. A pump forces the slip into the inverted ware for interior glazing and the outside may be coated with a brush or by dipping the article into the slip. The ware is coated with the slip before burning in the kiln so that the glazing and burning are accomplished in one operation.

The common slip clay is the Albany slip from the Hudson river, and its composition is given in Chapter IV. The slip is commonly used as a glaze without the addition of other materials. "Efforts have been made to lower the fusibility of the slip clay and make it run more easily without destroying its richness of color" according to Ries,¹ who gives the following recipe for such a glaze fusing at moderately low heat:

Albany slip clay.....	63.30 to 70.00
White Lead.....	25.30 to 17.00
Flint	6.30 to 7.00
Oxide of iron.....	0.72 to 0.79
Oxide of manganese.....	0.56 to 0.61
Chromate of lead.....	1.27 to 1.40
Chromate of iron.....	0.67 to 0.73
Oxide of zinc.....	1.88 to 2.07

The stone ware is set in up-draft or down-draft kilns usually circular. The pieces are set one over the other, separated by pieces of clay and placed so as to give a good draft through the kiln. The ware is burned 30 to 36 hours with coal fuel, 40 to 48 hours with wood fuel, and 40 to 50 hours with gas fuel. The temperature of burning ranges from 1800° to 2300° F.² Earthenware is not glazed and is burned in similar kilns to those used for stoneware, but at much lower temperature.

1. Bull. New York State Museum, No. 35 p. 808.

2. Bull. New York State Museum, No. 35, p. 809.

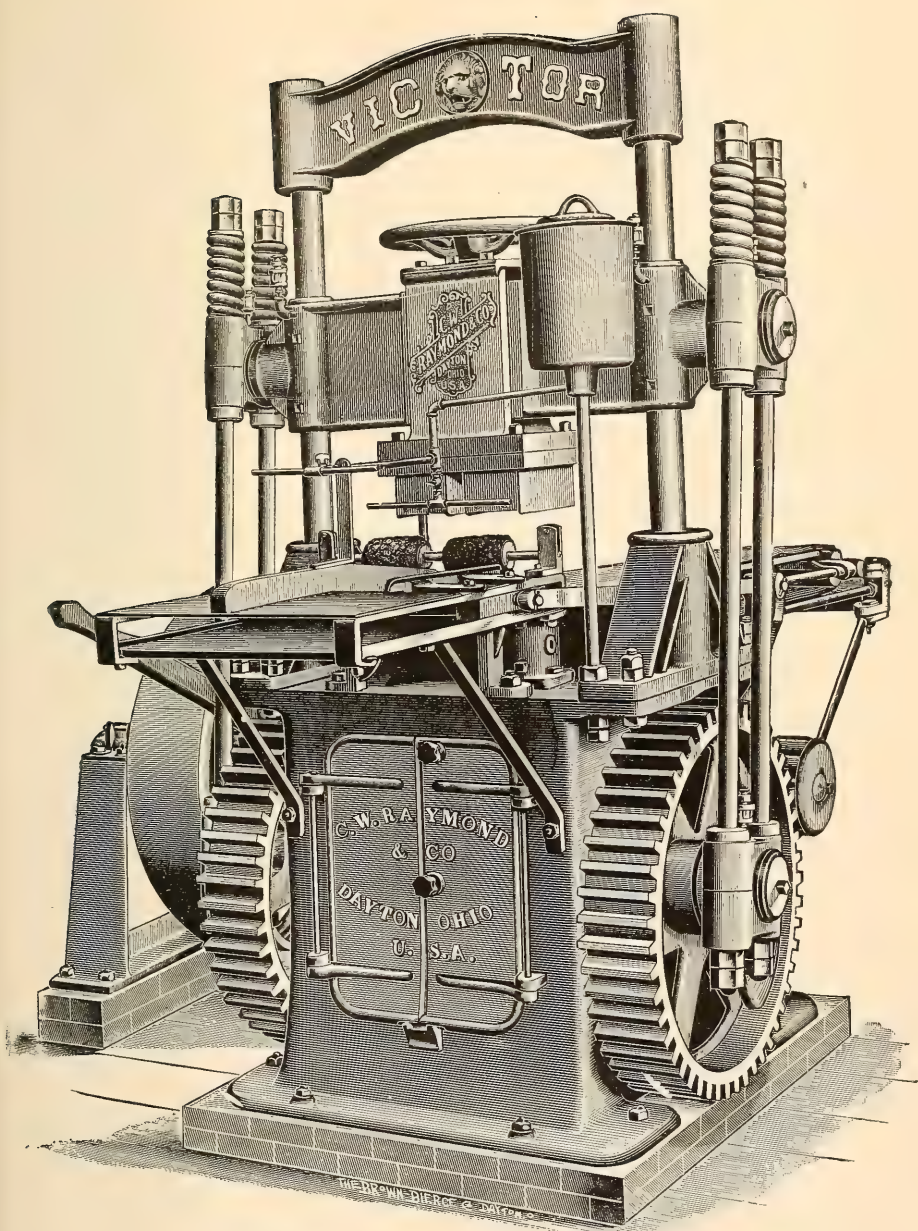


Plate X.—Victor Repress Brick Machine.

BURNING AND GLAZING OF WHITE GRANITE AND CHINA.

The C. C. ware, yellow ware, white granite, and china after drying are burned in "biscuit" kilns, 16 to 20 feet in diameter, tapering toward the top, for 50 to 60 hours. Muffle kilns are sometimes used to prevent the fuel gases from coming in contact with the ware, but more often the ware is placed in saggers which are made in the form of oval boxes with open top, made from fire clay mixed with grog (ground saggers or fire brick).

The saggers are glazed on the inside to prevent any gases passing from the sagger into the ware and in glazed ware to prevent the sagger clay absorbing the glaze from the ware. The saggers filled with ware are placed in the kiln, one over the other, forming muffles which prevent the fuel gases reaching the ware as is accomplished in the muffle kilns. After the articles are burned to a good porous body of fair degree of hardness they are removed and dipped in the glaze, then set in saggers in the glost kilns and burned 15 to 18 hours.

The glaze is made from a mixture of fusible clays and mineral oxides. White ware glazes are usually "fret" glazes, which are prepared by mixing the proper proportions of the substances, melting them and allowing the mixture to cool to a solid mass. These solid cakes are ground in a pebble mill, a cylindrical drum lined with hard wood and containing hard flint pebbles. When this machine is revolved the pebbles grind the hard cake to a fine flour which can then be mixed with water in glaze mills, screened and stored in the glaze tubs. In some plants the mass is ground in a grog mill which is a wet pan with heavy mullers.

The glazing of china is a delicate operation for there must be a careful adjustment in the shrinkage of the glaze and body of the ware, otherwise cracks will appear through the glaze. These cracks may appear at once or after some weeks' or months' time. The glaze should be as transparent as possible, flow evenly over the ware and have a pure color without tints.

DECORATION OF POTTERY.

Earthenware may be colored with blue and red colors, which are usually dull. Stoneware is rarely decorated. The glazed china and granite ware may be decorated with patterns painted with a

brush, by stencil patterns, or by transfer designs. This may be done before the glaze is applied, *under glaze*, or after the ware is glazed, *over glaze*. The former is the more durable, but the latter permits a greater variety of color. After the ware is decorated it is fired in the small decorating kilns for six to eight hours.

The colors are given by mineral oxides,¹ oxide of copper gives deep reds, or brilliant blues, and greens, according to the amount of oxidation; oxides of cobalt give blue and gray shades; oxide of antimony gives yellow; oxide of chromium gives green; oxide of manganese gives violet to black; oxides of iron give reds, yellow, browns. The oxides of iron, cobalt, and chromium, can be used for under glaze decoration. Oxide of lead, borax, potassium and sodium carbonates are used in the mixture for over glaze decoration as fluxes to bring about a combination with the glaze.

In the use of stencil patterns of decoration, careful work is required to match the stencil imprints so that no break in the continuity of the design may appear. The transfer designs are etched or cut in a copper plate and imprinted by a roller press on the soft mixture of the pigments and oils on tissue paper. This paper is then pressed into place on the ware and allowed to dry, when the paper can be washed off, leaving the design in pigment to be burned. ,

The gold designs are put on the ware with a brush. In the ordinary grades of china the work with brush is a copy of set designs and no marked originality of designs is attempted. In the fine art pottery skilled artists are employed and ware of great beauty and of high value is produced.

WEST VIRGINIA STONEWARE POTTERIES.

There have been established in this State a number of stoneware potteries which were operated for a number of years supplying a local trade, but were later abandoned.

At Martinsburg a pottery was in operation; also at Shinnston in Harrison county, where Wilkinson and Fleming made crocks, jugs, jars, and vases. On North river in Hampshire county and near Moorefield in Hardy, potteries were established as well as at Shepherdstown. At Palatine in Marion county, Knotts,

1. Encyclopedia Brittanica, vol. XIX, p. 643.

Swindler & Company, and on East river in Mercer county. Brown & McKenzie operated stoneware potteries.

MORGANTOWN, MONONGALIA COUNTY.

Probably the first pottery west of the Allegheny mountains was established at Morgantown sometime before 1785¹. Some years later this pottery became the property of John W. Thompson. The ware made was a porous terra cotta covered with a yellow lead glaze. Later the ware was covered with a transparent lead glaze forming the "red ware." In the early 40's stoneware was made glazed on the interior with Albany slip, and the outside decorated with blue was salt glazed. About this time the pottery was operated by Greenland Thompson, son of the former owner.

The exterior of the ware was ornamented with natural relief forms, the vases, pitchers, etc., were adorned with the impressions of rose stems, leaves, buds, etc., glazed with salt. The stoneware crocks, jars and jugs were decorated with rude floral ornaments in cobalt and salt glazed. This pottery ceased work on the death of its owner in 1890.

The clay used at this old Morgantown pottery was mined a few miles from town and was a river clay. The upper terrace of the Monongahela river near Morgantown contains deposits of pottery clay at a number of points near this place, which run from six to twelve feet in depth. Its composition is shown by the following analysis:

	Per cent.
Silica	63.32
Alumina	21.62
Ferric iron.....	1.99
Ferrous iron.....	0.37
Magnesia	0.45
Lime	0.22
Sodium	0.18
Potassium	2.45
Water	2.64
Titanium	1.12
Loss on ignition.....	5.54
	99.90

These deposits are near the Baltimore & Ohio railroad and the Monongahela river, with cheap gas fuel accessible.

1. An Early West Virginia Pottery, by Walter Hough, Report U. S. National Museum, 1899, pp. 511-521.

All of the stoneware potteries so far mentioned are now abandoned and there are only two plants in operation at the present time. At various places over the State are good deposits of earthenware and stoneware clays. Some of these have been examined in the course of this investigation, and many others have not as yet been visited. The river terrace clays at Morgantown, the river clays of many counties in the central and southern parts of the State, would make excellent grades of ware. The sites of the abandoned potteries listed above still contain good clays which were proved by actual trial to be valuable.

A small pottery using the local clay can supply a demand near at home and possibly prove in a small way a profitable investment to local people. With more capital, larger plants, and experienced potters, there is no reason why a large profitable stoneware industry should not exist in this State as in other states. The stoneware used in West Virginia should be made at home. The advantages of these valuable clays should be appreciated. Clays for the manufacture of high grade granite ware and china probably do not exist within the limits of this State, but the quantity of good earthenware and stoneware clays will probably prove on careful investigation to be almost unlimited. Yet at the present time this clay industry amounts to about \$10,000 a year when it should at least be ten times that amount.

In Ohio this industry amounts to about one million dollars, in Illinois, over one-half million; in Pennsylvania, nearly four hundred thousand dollars. The products are shipped from neighboring states by the car load into the towns and cities of West Virginia, while the home clays equal in value to those of other states remain unused.

PARKERSBURG, WOOD COUNTY.

Donahoue Pottery. This plant is located one and one-half miles above the center of the city of Parkersburg at the edge of town. It was built in 1866 and has been under the present ownership since 1874. The articles made are stoneware crocks, jugs, jars, earthenware, flower pots. The clay is ground in a wet pan, molded on two power wheels and one foot power wheel, and dried by steam in two large rooms for 48 hours. The ware is placed on long board shelves set on racks, where it is dried by steam.

The ware is burned in two conical up-draft kilns 13 feet high and 13 feet in diameter inside. The kilns are at each end of the frame building, containing the machinery and dry rooms. One kiln is used for salt glazed ware and the other is a muffle kiln for slip glazed ware. Wood and coal are used for fuel and the kilns are burned 30 to 48 hours. The capacity of the plant is about 5,000 gallons a week, equal to two kilns. Milk pans and flower pots are molded in plaster molds, while the other ware is turned by hand. Power is furnished by two gas engines. The product is sold in West Virginia and much of it is shipped to Virginia, South Carolina, and even into Ohio.

Clay. The clay is found a short distance back of the pottery and is hauled in dump carts. The old bank shows six to seven feet of pottery clay with six to eight feet of fine building sand over it covered by four or five feet of clay and sand. The building sand is sold in town so that the cost of stripping is much reduced.

In the new bank now opened the cover is much heavier, reaching 25 feet of sand and sandy clay with four feet of black earth or peat over the clay. When the pottery clay is traced to the west a short distance, it runs out and is replaced by sand. To the south an eighth of a mile it is claimed to be poor in quality, but it has been traced to the north for one-half mile. The location of this clay and pottery is about one-half mile from the Ohio river, probably 60 feet higher, and about the same distance from the Ohio river division of the Baltimore & Ohio railroad.

Chemical Analyses.—The Donahue pottery clay shows 'on analysis the following composition, which may be compared with the stoneware clay used at Zanesville, Ohio:

	Donahue clay.	Zanesville clay ¹ .
	Per cent.	Per cent.
Silica	73.33	64.26
Alumina	14.98	22.95
Ferrie iron.....	1.75 }	1.28
Ferrous iron.....	0.24 }	
Magnesium	0.45	0.37
Lime	0.43	0.45
Sodium	0.29	0.15
Potassium	1.93	1.81
Water	1.32	6.74
Titanium	0.81	....
Phosphorus	0.15	....
Loss on ignition.....	4.46	2.05
	100.14	100.06

1. Ohio Geol. Survey, vol. VII, p. 94.

The proportion of silica and alumina in the Parkersburg clay is 88.31 and in the Zanesville clay 87.21 per cent. The percentage of fluxes in the former is 5.09, and in the Ohio clay 4.06. Both are low in iron and lime. According to Orton a high percentage of lime would cause difficulty in securing an even salt glaze, as in drying the lime would be brought to the surface of the ware in the form of a soluble salt and leave a white coating. The salt vapors would be kept from contact with the clay wherever this white coat was present and so could not combine with the free silica of the clay at that place.

If the iron percentage is high the ware will have a varying color due to the degree of oxidation of the iron in the kiln so that it will be difficult to secure a uniform product. These difficulties do not apply to ware which is slip glazed.

A rational analysis of the Parkersburg clay gives:

Free silica.....	51.43	per cent.
Feldspar	6.16	" "
Clay substance.....	42.41	" "

The feldspar components act as a flux and a good percentage of free silica is essential for salt glazing as the salt vapor unites with the free silica to form the sodium silicate glaze. The amount of free silica in the Zanesville clay is 36.58 per cent.

A mechanical analysis shows the grades of fineness of the Parkersburg clay:

	Range in Millimeters.	Per cent.
Fine clay.....	0.000 to .001	21.85
Coarse clay.....	.001 to .005	11.5
Silt	.005 to .02	30.1
Fine sand.....	.02 to .15	33.75
Coarse sand.....	.15 to .5	1.5
Water		1.3

Physical Properties. The clay slakes in three minutes, its specific gravity is 2.58, the water required to develop a normal molding consistency is 25 per cent, its maximum plasticity is 19, its air shrinkage 6 per cent. The average tensile strength is 264 with a maximum of 286 pounds to the square inch. Incipient fusion begins near cone 1 and vitrification at cone 5, while the clay is viscous at cone ³⁰ 4. The color at all these temperatures is cream. The fire shrinkage at cone 1 is 3 per cent, and 3 per cent at cone 5.

BRIDGEPORT, HARRISON COUNTY.

West Virginia Pottery Company. The plant of this company is located at Bridgeport, six miles east of Clarksburg on the Baltimore & Ohio railroad, and was started in 1880.

This pottery makes all kinds of stoneware, jars, jugs, crocks, etc., also flower pots in earthenware. The present capacity is 1,000 gallons a day, but a new addition has been completed which will double the output.

The clay is ground in a Bonnot seven-foot wet pan and molded on three power wheels. The ware is dried in a large steam dry room and burned in a down-draft kiln, 18½ feet in diameter, with gas fuel. The kiln holds 6,000 gallons and is burned 50 to 60 hours. A new kiln has been added which is 22½ feet in diameter.

Clay Mine. The clay mine is located one and one-half miles east of the pottery and the clay is hauled in wagons. A section of the pit shows:

	Feet.	Inches.
Yellow clay cover (not used).....	2	6
White and brownish clay.....	4	0
Red iron streaked clay.....	1	0
Brownish white and drab clay.....	2	6
Iron streak shaly clay.....	0	2
Brownish white and drab clay.....	3	0

Along the north wall of the pit the drab clay is banded with parallel iron streaks, and on the west wall the clay contains considerable vegetable matter dark in color. The pit, as opened, is about 25 feet square and is located at the side of the county road on the Sandusky farm. Other small pits have been opened on neighboring tracts.

At the north edge of town on the J. H. Willis farm and adjoining farms, six to fourteen feet of pottery clay are found which covers probably 100 acres.. One test pit has been opened close to town and shows eight feet of good clay with three to four feet of cover. The clay is banded and in the lower part breaks in thin laminae along iron stained seams. All of these deposits are located on the sloping sides of ravines and the dried clay tends to break with prismatic jointing planes.

Chemical Analysis. The clay from the test pit near town was sampled and analyzed with the following result:

	Per cent.
Silica	60.34
Alumina	20.55
Ferric iron.....	3.53
Ferrous iron.....	0.49
Magnesium	1.12
Lime	0.38
Sodium	0.73
Potassium	2.89
Water	2.35
Titanium	0.92
Phosphorus	0.55
Loss on ignition.....	6.42
	100.27

The clay is higher in iron than the Parkersburg clay and contains 9.14 per cent of fluxing elements as compared with 5.09 at Parkersburg. The proportion of silica and alumina, 80.89 per cent, is lower. The percentage of lime is lower. The rational analysis shows considerable difference between this clay and the one at Parkersburg.

Free silica.....	25.16	per cent.
Feldspar	4.36	" "
Clay substance.....	70.48	" "

A mechanical analysis yields:

	Range in Millimeters.	Per cent
Fine clay.....	0.000 to .001	38.6
Coarse clay.....	.001 to .005	18.8
Silt	.005 to .02	34.4
Fine sand.....	.02 to .15	3.0
Coarse sand.....	.15 to 3.00	3.9
Water		2.3

This analysis shows a marked change from the Parkersburg clay in the percentage of particles between .02 to .15 and .15 to 3.0 millimeters in size.

RAVENSWOOD, JACKSON COUNTY.

East of Ravenswood one and one-half miles along the Spencer branch of the Baltimore & Ohio railroad on the J. M. Weas farm, in the old grading pit of the railroad, there is a deposit of pottery clay ten to twelve feet in depth resting on a sandstone floor.

Above this clay are ten to twelve feet of buff and blue clays covered by three feet of sandy loam. The pottery clay appears in the run, one-fourth of a mile east and was found in a well to the southeast. There is apparently a large area of the clay in this

valley, but no use has yet been made of it, though the large extent of the clay, its good quality, and nearness to the railroad should make it a valuable location for a large pottery.

Chemical Analyses. The pottery clay and the overlying clays have the following composition:

	Pottery clay, Per cent.	Overlying clay, Per cent.
Silica	51.11	60.90
Alumina	20.86	19.32
Ferric iron.....	2.87	6.95
Ferrous iron.....	3.50	0.50
Magnesium	2.08	0.92
Lime	4.19	0.22
Sodium	0.40	0.31
Potassium	3.49	3.04
Water	0.95	1.12
Titanium	0.84	0.84
Phosphorus	trace	trace
Loss on ignition.....	9.72	5.96
	100.01	100.08

By rational analysis the lower clay shows:

Free silica.....	21.09 per cent.
Feldspar	6.65 " "
Clay substance.....	72.26 " "

which compares favorably with the Bridgeport pottery clay.

The percentage of fluxes in the lower clay is 16.53, and in the upper clay 11.94, much higher than the pottery clays now worked. The percentage of ferric iron is not as high in the lower clay as at Bridgeport. The percentage of silica and alumina in the Ravenswood clays are 71.97 and 80.22. The two clays show on mechanical analysis:

	Range in Millimeters.	Lower clay. Per cent.	Upper clay. Per cent.
Fine clay.....	0.000 to .001	34.3	33.95
Coarse clay.....	.001 to .005	29.4	24.10
Silt	.005 to .02	35.0	24.00
Fine sand.....	.02 to .15	0.4	13.60
Coarse sand.....	.15 to 1.00	0.0	3.23
Water		0.9	1.10

These analyses show the pottery clay to be of very fine grain, while the upper clay is a little coarser, but both clays are above the average in grade of fineness.

Physical Properties. Both clays slake in three minutes and require 30 per cent. of water to develop a normal molding consistency. The maximum plasticity of the lower clay is 11 and of

the upper clay 14, and the air shrinkage of both is $5\frac{1}{2}$ per cent. The tensile strength of the lower clay is 154 pounds with a maximum of 161, or when weathered of 190 pounds. In the upper clay the average is 150 pounds, maximum 172, and when weathered reaches 202 pounds to the square inch. This clay heated to cone 05 shows a red color and shrinkage of 2 per cent., but no sign of vitrification, while at cone 1 it is vitrified with a shrinkage of 10 per cent., and greenish brown in color. It does not fuse at cone 5, but shows shrinkage of 10 per cent.

The detailed study of the county geology over the State in the future will, without doubt, show many other good deposits of pottery clays.

WEST VIRGINIA WHITE WARE POTTERIES.

No deposits of pure china clays have been discovered in the State, and they probably do not exist. Some of the purer plastic clays might possibly be used as binders in the china clay mixture, but they have not as yet been tried. There are no deposits of feldspar and none of quartz of any workable extent. The materials for the high grade china are lacking, but the State possesses a valuable and extensive supply of natural gas fuel, which is cheap and especially adapted to the burning of pottery.

The presence of valuable gas and coal fuel, the nearness to large markets and excellent transportation facilities have located one of the greatest white ware centers in this country in the upper Ohio valley in Ohio and West Virginia. Expert potters are clannish people and the center being established for large and numerous potteries, the question of supply of labor is solved in this district. The pottery industry of East Liverpool, Ohio, has extended over the river into the Pan-Handle of West Virginia. The offer of suitable building sites and cheap fuel has brought new potteries into other sections of the State. In addition to the old established plants of the Pan-Handle, new potteries have been established away from the river, others are in process of erection, and rumors of still other plants to be erected are attracting attention in various cities. The present output of these West Virginia potteries amounts to a million dollars a year. The materials for the ware are shipped in from Kentucky, Missouri, New Jersey, Maine, Georgia, Florida, South Carolina, and England.

CHESTER, HANCOCK COUNTY.

Edwin M. Knowles China Company. This plant is located at Chester, across the Ohio river from East Liverpool at the extreme northern end of the Pan-Handle. It was established in 1900 for the manufacture of semi-vitreous dinner and toilet ware, plain and decorated.

The plant is equipped with American Clay Working Company machinery, consisting of two blungers, agitators, screens, two filter presses, pug mill, jollies, lathes, etc. The ware is burned in three biscuit kilns, 18½ feet in diameter, three glost kilns 16½ feet in diameter, and the decorated ware in four decorating kilns. The annual output amounts to \$200,000 a year.

Taylor, Smith & Taylor Pottery. This plant is also located at Chester and was built in 1890. The equipment was made by the Crossley Manufacturing Company, and consists of three blungers, screens, agitators, two filter presses. The ware is burned in four biscuit kilns, 18 feet in diameter, five glost kilns, 16 feet in diameter, and the decorated ware burned in six decorating kilns. About 300 people are employed and the annual sales amount to \$300,000. The ware is semi-vitreous porcelain dinner and toilet sets and miscellaneous pieces.

At Newell, two miles from Chester, a very large china pottery is now in the course of construction.

NEW CUMBERLAND, HANCOCK COUNTY.

The Chelsea China Company built a plant of six kilns at the lower edge of the town of New Cumberland in 1889 for the manufacture of white china and decorated ware. This plant was burned in January, 1904. In the spring of 1905 the property was purchased by the Standard Porcelain Company, composed mainly of local stockholders. Two kilns are in use and the plant is devoted to the manufacture of electrical supplies. One branch of the work is the manufacture of porcelain lettered electrical signs made under patents controlled by this company.

WHEELING, OHIO COUNTY.

Warwick Pottery Company. This plant is located in the city of Wheeling and was established in 1887. The machinery used is the regular pottery equipment made by the Patterson Machine

Company. The ware is burned in seven biscuit and glost kilns, and in seven decorating kilns. While the company manufacture dinner and toilet ware, they make a specialty of ornaments and novelties.

Wheeling Pottery Company was the first white ware pottery established in West Virginia, beginning work in 1879. The company now owns two plants in the city of Wheeling devoted to the manufacture of table and toilet ware and novelties. One plant has eight kilns and the other twelve. They also operate a four kiln sanitary ware pottery at the north edge of the city. The three plants are combined under the name of Wheeling Potteries Company.

CLARKSBURG, HARRISON COUNTY.

The A. Radford Pottery Company was organized two years ago and has constructed a \$100,000 plant at Industrial, two miles east of Clarksburg. There are two biscuit kilns 15½ feet in diameter, two glost kilns of same diameter, and two 4-foot muffle decorating kilns. Patterson machinery is used through the plant. Plain and decorated table and toilet ware are made together with ornamental specialties. Two of the leading specialties are velvety art ware and Rooko ware, which have proved to be very popular. Gas fuel is used and the plant employs about 75 men.

HUNTINGTON, CABELL COUNTY.

The Huntington China Company has completed its plant and commenced the manufacture of table and toilet ware in August, 1905. They have three biscuit kilns 18½ feet in diameter, four glost kilns 16½ feet in diameter, and four double decorating kilns.

CAMERON, MARSHALL COUNTY.

At Cameron is a four kiln pottery engaged in the manufacture of table and toilet ware.

MANNINGTON, MARION COUNTY.

At Mannington a white ware pottery built a few years ago has been changed in 1904 to manufacture plumbers earthenware and sanitary specialties. The plant contains four bisque and four glost kilns, and when operated at full capacity employs 100 persons.

SEWER PIPE.

The clay or shale for sewer pipe must be plastic and have the property of burning to a hard body of good strength. They must have free silica to unite with salt and form a glazed surface. Sewer pipe of a dark red or brown color is usually preferred by the trade, so the iron percentage should be high. Where it is low, other clays high in iron are added, and in some cases manganese is added with the salt.

METHOD OF MANUFACTURE.

The materials are ground and tempered in wet pans or chaser mills, and the process must be very thorough to secure an even mixture in order that the shrinkage may be at a minimum and uniform, and prevent any warping or cracking in burning.

The factory is usually built three stories high, giving three drying floors, with the press near the center one. The clay is elevated from the wet pan to storage bins above the press, or in small plants it is brought to the level of the press and shoveled into it.

The sewer pipe press consists of two vertical cylinders, one over the other, supported by heavy wood or steel framework. The upper steam cylinder is 28 to 52 inches in diameter, the usual size being 40 inches. The lower clay cylinder is 14 inches to 28 inches in diameter. The piston or pistons in the steam cylinder have a 27 to 72-inch stroke, and the presses, according to their size, will make pipe from 2 to 42 inches in diameter. The pistons of the steam cylinder are connected with the clay piston or plunger, which is made to fit the interior of the cylinder, provided with removable wearing parts. The whole mechanism is provided with safety valves and appliances, and works under a pressure of 100 to 125 pounds.

At the bottom of the clay cylinder is a casting called the *spider* which supports the mechanical cut off, and the inside *bell* or die which regulates the interior diameter of the pipe. A balanced table below is set on a tube which can be raised or lowered on guide rolls and receives the pipe from the press. The sewer pipe press is illustrated in plate XVI.

In operation, the clay cylinder is filled with clay from bins above, or by a feed belt, or shoveled in by hand. The steam pistons slowly push down the clay plunger forcing the clay out

through the die as a stiff mud cylinder which is cut off into lengths of two to three feet by a wire or knife operated by hand or automatic. The sockets or flanges of the pipe are made by a "socket former" fastened to the end of the die, and when filled, the clay passes out through the trial openings in the ring which is then unclamped and the clay cylinder issues with its standard size.

According to Orton¹ seven or eight men form a press gang, though the number may be reduced by automatic devices, and in a day's continuous run they will make the following amount of pipe:

24-inch pipe.....	350	pieces	per	day.
20 " "	450	"	"	"
18 " "	550	"	"	"
15 " "	800	"	"	"
10 " "	1200	"	"	"
8 " "	1800	"	"	"
6 " "	2200	"	"	"
4 " "	3500	"	"	"

The smaller pipe are placed on wooden pallets set on platform trucks and wheeled to the drying floor, while large pipe are transported on spring saddle trucks. The pipe are allowed to dry a few hours in a warm room or on the drying floor, and are then trimmed, sponged smooth, and any small cracks mended. Special shapes of pipe as traps, elbows, etc., are made by hand in plaster molds. The pipe are dried on slat floors heated by steam or hot air, an operation which requires great care in raising the temperature, or they will be cracked.

Sewer pipe are burned in round down-draft kilns, 26 to 30 feet in diameter, for four to six days. The pipe are set vertical in the kiln and the smaller sizes are stacked inside the larger, care being taken that the pipe do not touch each other, which would protect the contact surface from the glaze.

When the temperature is highest the fires are salted by throwing in salt one or two times over the grates, the amount required for a kiln being 150 pounds or more. The salt (chloride of sodium) unites with the free silica of the ware and forms the sodium silicate glaze which gives a brighter color to the ware, fills the pores and gives a smooth finish.

After salting, the kilns are closed and allowed to cool three or four days, the kilns are opened gradually to complete the cooling

1. Ohio Geological Survey, Vol. VII., p. 211.

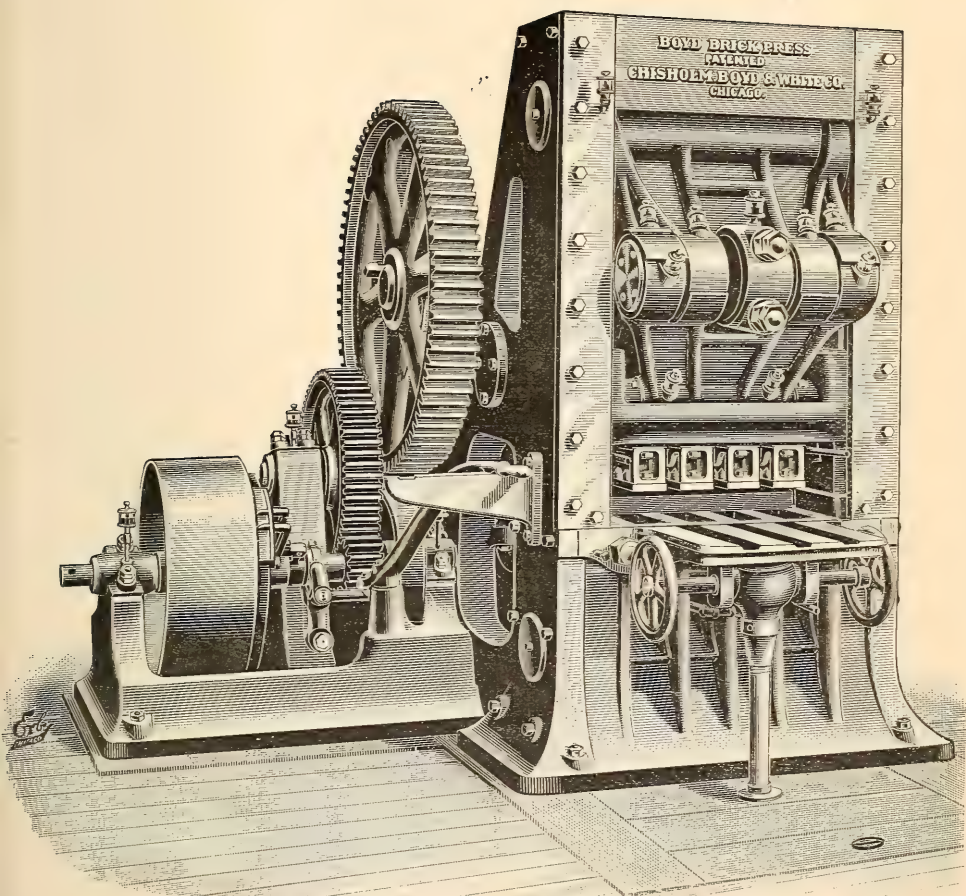


Plate XI.—Boyd Dry Press Brick Machine.

and prevent any cracking. The pipe are then removed and sorted. Any ware showing defects of glaze, iron spots, blisters, or lack of uniformity in color, are classed as *seconds*, commanding a lower market price, though they may be as strong, durable, and serviceable as the first grade.

The demand for carloads of varying size and shaped pipe, and the greater demand in spring and summer, require the plants to make much surplus stock, requiring large storage yards around the plants. (See lower part of plate XIII.)

SEWER PIPE PLANTS IN WEST VIRGINIA.

The sewer pipe plants of this country are combined through a selling agreement, so that the supply for certain seasons comes from one group of plants and at other times from another group, with a satisfactory arrangement of remuneration to all. As a result the plants in this State have not been in operation for the past few years. The equipment is retained and they may be re-opened at any time. The quality of sewer pipe made at these plants is of the highest grade, and it is unfortunate for the clay industry of this State that they are closed down.

The West Virginia sewer pipe factories are all located near New Cumberland in the northern Panhandle, and include the Eagle, Clifton, and Sligo works of the Mack Company, and the plant of the American Sewer Pipe Company. The Kittanning clays were used, and a description of these plants with analyses of the clays will be given in chapter VIII. The Clifton plant has been in operation during the season of 1905.

CHAPTER VII.

RESUME OF THE TOPOGRAPHY AND GEOLOGY OF WEST VIRGINIA.

INTRODUCTION.

The facts given in the discussion of the topography and geology of West Virginia are not new. They can be found in a number of reports, the description of the Carboniferous division being given in a much more detailed form in volume II. of the reports of this survey.

It was deemed advisable to collate these accounts in compact form so as to be available to the readers of this volume who may not have access to the other reports for this information; and in order that the reader may have conveniently at hand an account of the topographical and geological conditions of the State, that he may better appreciate the location of these valuable clay deposits and the natural advantages present for their successful development.

The State of West Virginia is naturally enclosed by the mountain barriers at the east, the Ohio and Big Sandy rivers at the west and south, while its northern boundary, with the exception of the Panhandle, is marked by the Mason and Dixon line, and Potomac river.

Its length from north to south is 241 miles, its greatest breadth is 158 miles, and its longest distance from northeast to southwest is 274 miles. The area of the state¹ is 24,780 square miles, or 15,859,200 acres, of which 135 square miles is water surface. Of the land area 10,654,513 acres are in farms, and one-half of these under cultivation. There are 18,400 square miles, or 11,776,000 acres of timber land (part of this being included in the uncultivated farm area), and the coal area covers 17,280 square miles or 11,059,200 acres. The population is over 1,000,000; the railroad mileage 4,000, and 51 of the 55 counties have

1. Statistics from U. S. Geol. Survey, Bull. 233.

railroad connection. There are four rivers equipped with government dams and locks: Big Sandy, Great Kanawha, Little Kanawha, and Monongahela, giving 300 miles of navigable water. These all connect with the Ohio river, which runs along the western side of the State for a distance of 256 miles, affording water transportation to the southwest.

The State has valuable fuel deposits of coal, oil, gas, large deposits of high grade clays adapted to the manufacture of refractory, paving, pottery, and structural materials, and also numerous railroads and water ways connecting the various sections of the State with the markets of large cities located near its borders. The northern part of the State is 90 miles from Pittsburg by water and rail; Kenova, at the southwestern corner, is 150 miles from Cincinnati by water and rail; Harper's Ferry, at the eastern side, is 56 miles from Washington by water and rail, 81 miles from Baltimore, 175 miles from Philadelphia, 273 miles from New York; Hinton, on New river, is 396 miles from Norfolk and 311 miles from Richmond by rail. Kentucky and Ohio ship fire clay, brick and various clay products into this State and across it to eastern markets.

TOPOGRAPHY OF WEST VIRGINIA.

The altitude of West Virginia varies from 4,860 feet above sea at Spruce Knob Pendleton county to 280 feet at Harper's Ferry. The mean altitude is 1,500 feet, the average annual temperature is 52.3 degrees. The areas of the State at the different altitudes are given in the following table:¹

	Square Miles.
500-1,000	7,900
1,000-1,500	6,000
1,500-2,000	4,200
2,000-3,000	5,280
3,000-4,000	1,200
4,000-5,000	200

The State is described topographically as a highly dissected portion of the Allegheny plateau sloping to the valley of the Ohio, and popularly described by its citizens as the "Little Mountain State."

The greater portion of the State consists of hills or mountains of varying height separated by deep cut valleys. At the

1. U. S. Geol. Survey, Bull. No. 233, p. 6.

west in the valley of the Ohio the hills are low, while at the east in the Alleghenies high peaks and ridges cut by tortuous canyons furnish wild and rugged scenery, changing at the northeast into the calm and beautiful valley of the Potomac and Shenandoah. There are thus three well marked topographical divisions in the State.

1. The Ohio Valley.
2. The Allegheny Dissected Plateau.
3. The Potomac Valley.

THE OHIO VALLEY.

In this division are included the counties in the western part of the State bordering on the Ohio and extending eastward to the higher plateau, 1,500 to 2,000 feet in eastern Monongalia, Barbour, Upshur, eastern Kanawha, and Logan counties, the eastern boundary line having approximately a N. 40° E. direction.

This area includes the larger cities of the State, Charleston, Huntington, Parkersburg and Wheeling. It includes all of the famous Pittsburg coal area and the larger part of the Allegheny-Kanawha coal area, all of the developed oil and gas area. It is therefore the area of manufacturing plants. Its rocks are characterized by sandstone ledges with only thin limestones, and the area includes most of the developed clay deposits.

With the exception of the eastern Panhandle, it is the great agricultural section of the State, the leading corn and oats section. The leading wheat counties are found here and in the northeastern section of the State.

This Ohio Valley region contains over one-half of the total population of the State, and its area is about half the entire State. It is traversed by the largest rivers, and these with their almost innumerable branches and sub-branches, receiving an abundant supply of water from the mountain highlands, have sculptured the area into an intricate pattern of hills and ravines affording mountain scenery in miniature. These hills range from 100 to 1,000 feet in height, while a few knobs reach 1,674 and 1,720 feet (Bragg Knob in Clay county, High Knob in Braxton county).

The rivers furnish water transportation to the Ohio while their valleys afford easy grades for the railroads to enter all parts of the area, and in places the water in its descent affords a cheap

power for industrial plants. The more prominent rivers in this section are the Big Sandy, Twelve Pole, Guyandot, Great Kanawha, Little Kanawha, and Monongahela. They all flow into the Ohio, and with the exception of the last named river, they flow northeastward in nearly parallel courses. From these streams branch smaller streams, and from these, smaller and smaller creeks and runs, forming the wonderful network of the drainage system which is essential for a productive state.

The Big Sandy with its tributary, Tug Fork, forms the boundary line between West Virginia and Kentucky. It flows along the border for 130 miles and empties into the Ohio near Kenova, and is a navigable stream. Twelve Pole river rises in Mingo county and flows through Wayne, emptying into the Ohio above Kenova. Its length is 60 miles.

The Guyandot river has its source in Wyoming county and flows 130 miles northwest through Logan, Lincoln and Cabell counties, reaching the Ohio near Huntington, at Guyandotte. The fall from Logan to the mouth of the river, a distance of 70 miles, is 115 feet, while its total fall from its mountain source is 1,500 feet.

The Great Kanawha is formed by the union of the Gauley and New rivers in the western part of Fayette county and flows northeast through Kanawha, Putnam and Mason counties, emptying into the Ohio at Point Pleasant. Its length is about 90 miles and it is navigable nearly to its source. The elevation at Gauley is 650 feet, and at Point Pleasant, 560 feet, giving a fall of 90 feet in the 90 miles. The falls, a few miles below the mouth of the Gauley, have a height of 20 feet.

At Charleston enters the largest tributary of this river, the Elk, which has its source near Spruce Knob in the northern part of Pocahontas county almost due east of its mouth at Charleston. It rises near one of the highest points in the State, Spruce Knob, reaching a height of 4,730 feet. The Elk river follows a very winding path through Webster county to Sutton in Braxton, a point 25 miles north of its source, where it turns westward for 100 miles through Braxton, Clay, and Kanawha counties. Its length is not far from 175 miles, its level is 552 feet at Charleston, and 3,500 feet in Pocahontas county, or a fall of nearly 3,000 feet.

The Little Kanawha river heads in western Upshur county and flows 165 miles through Braxton, Gilmer, Calhoun, Wirt and

Wood counties, emptying into the Ohio at Parkersburg. The elevation at its source is 2,000 feet and 563 at its mouth, or a fall of 1,400 feet. It is a navigable stream for 50 miles.

The Monongahela river is formed by the union of the West Fork and Tygarts Valley at Fairmont, and flows northeast through Marion and Monongalia counties, then north through Pennsylvania to McKeesport, from which point it flows northwest to Pittsburg, where it unites with the Allegheny river to form the Ohio. It is navigable its entire distance and has a fall of 50 feet from Fairmont to the State line in a distance of 40 miles.

The West Fork river rises in the southern part of Lewis county and flows north to Fairmont. The Tygarts Valley river is formed by the union of several small creeks in southern Randolph county, and flows north to Elkins, thence north and northwest through Barbour and Taylor counties to Fairmont.

Nearly all these rivers in the Ohio Valley rise in the mountain highland and flow in winding courses across the valley. About six-sevenths of the area of the State is drained into the Ohio and about 3,500 square miles drain to the east through the Potomac.

ALLEGHENY PLATEAU.

The Allegheny Plateau is a highly dissected region 1,600 to 3,000 feet in elevation with higher peaks reaching 4,860 feet, and mountain ridges trending northeast-southwest. This plateau includes all of the eastern half of the State except the northeastern portion.

This area includes the great timber belt of the State. The entire lumber industry amounts to nearly \$12,000,000 yearly, with over 400 logging camps and a thousand saw mills. According to the U. S. census for 1900, there remain in the State about 35,000,000,000 feet B. M., and about one-half billion feet are cut a year, so that at the present rate of consumption the supply would last 70 years. On the higher portions of the plateau grow spruce, white pine, hemlock, and some hard woods, while the lower slopes are timbered especially with hard woods, walnut, sycamore, oaks, maple, hickory, elm, and ash.

The area includes all of the Pocahontas coal area, 700 square miles of high grade nearly smokeless steam coal. This coal is in

great demand for steamship and naval supplies. It includes also the large area of Greenbrier limestone and very important iron ore deposits. Its clays are of high value, including some of the best in the State, but up to the present time worked at but few places.

The important rivers at the south are the New, Gauley, and Greenbrier; and at the north the Cheat river. The area also furnishes the headwaters of nearly all the rivers of the Ohio valley and of the Potomac. It has been termed the "birth place of rivers."

The New river enters the State from old Virginia in Summers county and flows northwest 85 miles to the Gauley with a fall of 350 feet, or four feet to the mile. The Gauley rises in the eastern part of Webster county and flows 110 miles southwest, where it unites with the New river to form the Great Kanawha. It has a fall in this distance of 1,600 feet through canyons and over rapids of remarkable beauty and grandeur.

The Greenbrier rises in Randolph county and flows southwest through Pocahontas, Greenbrier, and at Hinton in Summers county empties into the New river. It is 160 miles in length, with 1,700 feet of fall. For 40 miles the Cheat river, flowing northward, and the Greenbrier, flowing southward, are only from two to four miles apart, separated by the Allegheny mountains, the waters of both reaching the Ohio by widely divergent paths.

The Cheat river rises near Bald Knob in the northwestern corner of Pocahontas county at an elevation of 3,000 feet, and flows north 175 miles through Randolph and Tucker counties to the middle of Preston, where it turns northwest and empties into the Monongahela just north of the state line at an elevation of 815 feet. The river is about 175 miles long with a fall of 2,200 feet, or 12 feet to the mile.

THE POTOMAC VALLEY.

The eastern Panhandle of the State includes the counties of Morgan, Berkeley and Jefferson. These counties with Hampshire, parts of Mineral, Grant and Hardy, lie in the valley of the Potomac, 280 to about 600 feet above tide. This includes the area of oldest rocks in the State, the Cambro-Silurian limestones, slates, and sandstone. It includes the lime and great limestone

industries of the State and possesses large and profitable cement resources which have been very slightly developed.

This valley includes an area of about 2,000 square miles with a population of 100,000. It is a rich limestone farming region and one of the great fruit belts of the State.

All of these counties border at the north on the Potomac and are crossed by the various tributary feeders of this historic river, as the South Branch of the Potomac, Little Cacapon, and Cacapon, and on the south side of Jefferson county is the Shenandoah river.

In this area is the oldest town in the State, Shepherdstown, established in 1727; the oldest county, Hampshire, formed in 1754. The rugged scenery of the Allegheny Plateau here gives place to the rolling fields covered with grasses and marked by cultivated farm plots, a restful, peaceful valley far famed for its quiet beauty and southern homes.

TRANSPORTATION LINES.

The waterways described above afford 600 miles of navigable water, improved by the national government. Up and down these streams ply the packets and barges bringing in supplies and taking out to the marts of the world the natural products of a prosperous State, wealthy in nature's endowments, buried in the earth and growing above in a free air.

Four thousand miles of railroads penetrate its hills and cross its valleys. The State is crossed by three trunk lines and soon will have a fourth. The Baltimore & Ohio at the north connecting at the east with Washington, Baltimore, Philadelphia, and New York, and at these points with steamers to all parts of the world; and at the west with Chicago and St. Louis, the gateways of the great West. The branches of this great and oldest system stretch out like fingers in all directions to collect and remove the products of soil and mine.

At the south are the Chesapeake & Ohio and Norfolk & Western railroads, connecting the State with Cincinnati and various cities in Ohio and Kentucky, while eastward they reach the coast and cities en route.

The links of the Wabash will soon be welded at the north, giving another outlet to Baltimore tidewater, and through Wheeling connecting with the cities of the west.

In addition to these trunk lines are the valuable local lines of the Kanawha and Michigan, Little Kanawha, Coal & Coke, Coal & Iron, West Virginia Central, Dry Fork, Morgantown & Kingwood, and other lines, built into almost inaccessible places, there to develop a dormant wealth of natural resources. New lines are building and other as yet on paper will be constructed, bringing wealth and comfort to mountain recesses.

GEOLOGY OF WEST VIRGINIA.

The rocks of the earth's surface have been classified by geologists in a series of division based for the most part on the life of past ages as preserved in a fossil state in these rocks. The main divisions of the geological column so constructed on these characters are as follows:

Cenozoic.—Recent life forms.

Mesozoic.—Less recent forms.

Paleozoic.—Oldest forms of life.

Archaean.—Crystalline rocks, with no undisputed evidence of life.

The geology of West Virginia is included in the Paleozoic division, and the greater portion of the State consists of rocks belonging to one subdivision of this area, the Carboniferous. The subdivisions of the Paleozoic are:

Carboniferous,

Devonian,

Silurian,

Cambrian.

A brief review of these groups of Paleozoic rocks in this State will now be given, starting with the lowest member, the Cambrian. As has been stated, this review is a compilation; for the Cambrian and Silurian from the report of Arthur Keith, on the Harpers Ferry folio of the United States Geological Survey, for the Silurian and Devonian from the report of N. H. Darton in the Piedmont and Franklin folios of the same survey, and for the Carboniferous from Dr. I. C. White's report on coal, forming volume II. of the reports of the Geological Survey of West Virginia.

TABLE OF GEOLOGICAL FORMATIONS IN WEST VIRGINIA.

CARBONIFEROUS:

Dunkard or Permo-Carboniferous**Series (1100-1200 feet).**

Windy Gap Limestone.
Windy Gap Coal.
Gilmore Sandstone.
Nineveh Sandstone.
Nineveh Coal.
Nineveh Limestone.
Fish Creek Sandstone.
Dunkard Coal.
Jollytown Coal.
Washington Limestone.
Marietta Sandstones.
Washington Stage.
Waynesburg Sandstone.
Cassville Plant Shale.

Monongahela Series (260-400 feet).

Waynesburg Coal.
Gilboy Sandstone.
Uniontown Coal.
The Great Limestone.
Sewickley Sandstone.
Sewickley Coal.
Sewickley Limestone.
Redstone Coal.
Redstone Limestone.
Pittsburg Sandstone.
Pittsburg Coal.

Conemaugh Series (600 feet).

Pittsburg Limestones.
Little Pittsburg Coals.
Connellsville Sandstone.
Little Clarksburg Coal.
Clarksburg Limestone.
Morgantown Sandstone.
Elk Lick Coal.
Elk Lick Limestone.
Birmingham Shale.
Ames Limestone.
Pittsburg Red Shale.
Saltzburg Sandstone.
Bakerstown Coal.
Upper Cambridge Limestone.
Buffalo Sandstone.
Lower Cambridge Limestone.
Brush Creek Coal.
Upper Mahoning Sandstone.
Mahoning Coal.
Lower Mahoning Sandstone.

Allegheny Series (225 to 600 feet). Kanawha Series (1,000 feet).

Upper Freeport Coal.	Charleston Sandstone.
Upper Freeport Limestone.	Two-Mile Limestone.
Roaring Creek Sandstone.	North Coalburg Coal (Mason).
Lower Freeport Coal.	No. 5 Block Coal.
Lower Freeport Limestone.	Kanawha Black Flint.
Lower Freeport Sandstone.	Stockton Coal.
Upper Kittanning Coal.	Coalburg Coal.
Middle Kittanning Coal.	Winifrede Coal.
Lower Kittanning Coal.	Cedar Grove Coal.
Lower Kittanning Sandstone.	Campbell's Creek Coal.
Ferriferous Limestone.	Brownstown Coal.
Clarion Sandstone.	Cannelton (Stockton) Limestone.
Clarion Coal.	Eagle Limestone ('Black Marble').

Pottsville Series.**Northern Section (250-300 feet).**

Homewood Sandstone.
 Mount Savage Fire Clay.
 Mount Savage Coal.
 Upper Mercer Coal.
 Lower Mercer Coal.
 Upper Connoquenessing Sandstone.
 Quakertown Coal.
 Lower Connoquenessing Sandstone.
 Sharon Coal.
 Sharon Conglomerate.

New River Section (1,200-2,000 feet).

Nuttall Sandstone.
 Sewell Coal.
 Welch Coal.
 Raleigh Sandstone.
 Beckley Coal.
 Quinimont Coal.
 Horsepen Coals.
 Pocahontas Coals (Nos. 4 to 1).

Lower Carboniferous Series, (950 to 4,000 feet).

Mauch Chunk Shales (300 to 2,000 feet).
 Greenbrier Limestone (150 to 800 feet).
 Pocono Sandstone, (500 to 1,200 feet).

DEVONIAN.

Catskill Sandstone (Hampshire, U. S. G. S.) 2,000 feet.
 Chemung Shales (Jennings, U. S. G. S.), 2,500 feet.
 Hamilton Shales (Romney, U. S. G. S.), 1,200 feet.
 Oriskany Sandstone (Monterey, U. S. G. S.), 250 feet.

UPPER SILURIAN.

Lower Helderberg Limestone }
 Salina Limestone and Shales } (Lewiston U. S. G. S.) 1,200 feet.

Clinton Limestone { Rockwood U. S. G. S. } 800 feet.
 { Cacapon U. S. G. S. }

Medina { White Sandstone (Tuscarora U. S. G. S.) } 1,000 feet.
 { Red Sandstone (Juniata U. S. G. S.) }

LOWER SILURIAN.

Martinsburg Shale (Hudson River), 2,000 feet.
 Shenandoah Limestone (in part), 1,000 feet.

CAMBRIAN.

Shenandoah Limestone (in part) 1,000 feet.
 Harper's Shale (1,200 feet).

CAMBRIAN.

In the eastern Panhandle of the State in the Valley of Virginia, the area is covered with limestone, shale, and some sandstone, which in age belong to the Cambrian and Silurian, or the first of the fossil bearing formations in the geological scale. These formations have been named by the United States Geological Survey from places where the rocks are well exposed.

Harpers Shale.—The lowest group of rocks in this section, and therefore in the State, is a series of shales named from Harpers Ferry, the *Harpers shale*. It is found in this State in a small area in Jefferson county around Harpers Ferry. Its characters, according to Keith, are a very uniform texture and composition, a dull bluish-gray color, but weathering to a light greenish-gray, and sandy. These are clay shales with small grains of quartz and feldspar, and small microscopic grains of epidote and magnetite minerals. The rocks are much twisted and compressed and have a probable thickness in complete section of 1,200 feet. The soil is only of fair value.

Above the Harpers shale comes the *Antietam sandstone*, usually white in color and composed of small grains of well worn white quartz fragments. While an important member of the series in Maryland, it is practically absent in this State.

Shenandoah Limestone.—This is one of the great limestones of the Appalachians and extends from New York to Alabama. It is found in the northeastern part of the State in the Potomac valley. Its upper layers contain fossil shells, corals, and crinoids of Lower Silurian age, while its lower layers contain shells and trilobites of Lower Cambrian age. The line of division between the Cambrian and Silurian in this limestone is not known so it is usually given as Cambro-Silurian in age.

The formation consists of blue, gray, and white limestones and dolomites with a chemical composition ranging from 44 to 98 per cent. of lime carbonates, and 2 to 42 per cent. of magnesia carbonate, with a thickness of over 1,000 feet. The purest limestone and the dolomite have the following composition :

	Limestone.	Dolomite.
Lime carbonate	99.07	54.72
Magnesium carbonate	0.31	39.18
Silica	0.25	0.05
Iron and alumina	0.37	0.89
Alkalies		0.15

The beds have been little altered and no marble is found in the State in this formation. The limestone weathers more rapidly than the other rocks of the area, through the solution of its carbonates, and forms a red clay of considerable depth. The soil is of exceptional fertility, making its area one of the best agricultural sections in the State.

The Shenandoah limestone has an important economic value for building stone, road material, limestone flux, lime, in places for natural cement, and in other sections is adapted to the manufacture of Portland cement. In the residual clays from this limestone occur lumps and nodules of limonite iron ore which contain 40 to 60 per cent. of iron that is mined at a few places on a small scale.

SILURIAN.

Martinsburg Shale.—This formation is best developed in the vicinity of Martinsburg in Berkeley county. It consists of black and gray limy and clayey shales. Its chemical composition as determined by the State survey is:

	Per cent.
Silica (SiO_2).....	53.30
Alumina (Al_2O_3).....	18.16
Iron (Fe_2O_3) and (FeO).....	6.53
Magnesia (MgO).....	2.65
Lime (CaO).....	4.89
Alkalies (Na_2O & K_2O).....	4.52
Water (H_2O).....	0.68
Titanium (TiO_2).....	0.72
Phosphorus (P_2O_5).....	0.24
Sulphur	0.77
Loss on ignition.....	7.36

On weathering the shale forms a yellow or brown clay soil of shallow depth of fair degree of fertility. The shales lie in synclinal troughs or folds in the limestone, and are folded and crumpled. They have cleavage planes developed and represent more or less metamorphosed slates. Several companies have been recently organized to work these slates. One equipped mill is in operation with a quarry 65 feet deep. Portions of this slate appear to be well adapted to interior work and can be secured in large slabs, taking a high polish and of good deep color. It would seem doubtful whether they could be used for roofing slate unless better material can be found with depth than appears near the

surface. These shales are, however, adapted to manufacture of Portland cement in connection with the neighboring limestone, and the weathered shales are used for brick.

Medina.—The Medina, or as it is called in the government folios the Juniata and Tuscarora, follows the mountain folds through Mineral, Grant, Hardy and Pendleton counties, and consists near the bottom of red sandstones, red shales, and white quartz rock near the top, and reaches a thickness of 1,230 feet in complete sections.

Clinton.—The Clinton is named in the government folios the Cacapon sandstone and Rockwood formation above. They are found along the slopes of the mountains in the above counties forming a narrow belt. The sandstone is a red flag stone with a thickness of 300 feet. The Rockwood formation above consists of a series of brown and gray shales with thin layers of sandstones and limestones. The thickness varies from 525 to 750 feet, and the shales are often crumpled. Deposits of iron ore occur in the latter formation along the slopes of New Creek Mountain, and in small areas in the center of Patterson Creek Mountain, and in North Fork and South Fork Mountains, but the surface beds are thin, and have not been investigated to any depth.

Helderberg or Lewiston Limestone.—The upper member of this formation consists of cherty limestone, and the lower member has a number of flaggy limestones, while the intermediate beds are softer, shaly and massive limestones. At the base are 250 feet of lime shales and thin bedded, impure limestones. The total thickness is 1,350 to 1,700 feet. The formation outcrops in Mineral and Grant counties along both sides of New Creek Mountain and forms the central part of Patterson Creek Mountain. At the south in Pendleton county it covers considerable areas on the slopes of North Fork and South Fork Mountains.

The upper layers carry important beds of natural cement rock which are worked near Hancock and Cumberland. The better grades of this limestone could be used for lime and flux, while the cherty layers, constituting about one-fourth of the entire thickness, would make good road material, as it disintegrates into hard angular fragments.

DEVONIAN.

Oriskany Sandstone.—The Oriskany (Monterey) sandstone is found just outside the outcrop of the preceding formation. It is a very hard, fine grained, calcareous sandstone, of dark gray or blue-gray color, which weathers to a buff, porous, sandy rock, and shows a variety of casts and impressions of fossil shells. In thickness it varies from 215 to 300 feet, and its resistant character causes it to remain in ridges and knobs, while in the path of streams it forms waterfalls and narrow gorges.

Hamilton (Romney) Shale.—Over the Oriskany come 1,200 feet of shales, dark and fissile below, and lighter and more compact above. They extend along the mountain slopes through Mineral, Grant, Hardy, Pendleton, Preston, Tucker, and Randolph counties, and on account of easy weathering and erosion form valleys or low rounded hills.

Chemung (Jennings) Formation.—This formation outcrops in the valleys just outside the Hamilton. The lower beds are light colored shales with interbedded light colored sandstones. The upper beds are gray sandstone with occasional conglomerate lenses, with a total thickness of 3,300 feet. It forms a large part of the valley between New Creek and Patterson Creek Mountains, and the western slope of North Mountain.

Catskill (Hampshire) Formation.—This formation is found along the middle slopes of the Allegheny front through Mineral, Grant, Pendleton, Randolph, and Tucker counties, passing to the west under the Carboniferous. It consists of sandstone and shale of red color. The sandstone forms masses 15 to 20 feet thick, often cross bedded. The masses of shale range from a few inches to 15 feet in thickness and the total thickness of the formation is 2,000 to 2,300 feet.

CARBONIFEROUS.

LOWER CARBONIFEROUS.

Pocono Sandstone.—This formation makes the base of the Carboniferous and outcrops along the slopes of the mountains through the counties of Mineral, Grant, Pendleton, Randolph, and Tucker, forming a series of knobs. It consists of a hard

sandstone or quartzite which is generally pebbly or conglomerate in character. The thickness varies from 300 to 800 feet.

Greenbrier Limestone.—This formation consists of thin and massive limestones with interbedded clay shales reaching 150 to 1,200 feet in thickness. Its outcrop forms an irregular line. It extends as a long narrow area bordering the Allegheny front through Mineral and Grant counties, and in larger masses through Pendleton, Pocahontas, Greenbrier, Monroe, Summers, Mercer, Randolph, Tucker, and Preston counties. It is valuable for ballast and building stone. It is used in the manufacture of Portland cement in Preston county and has been burned for lime near Hendricks in Tucker and Fort Spring in Greenbrier county. It is often very impure and in other sections of high degree of purity.

Mauch Chunk Shales.—This group consists of red and brown shales with green sandstone layers, especially in its upper portion. Its thickness at the north reaches 300 to 700 feet, and 2,500 feet at the south, but thins westward. It is found in the sections where the Greenbrier limestone outcrops.

MIDDLE AND UPPER CARBONIFEROUS.

The rocks now to be described constitute the coal measures of the State and they cover the central and western parts of it. For more detailed information than is given in this outline the reader is referred to volume II. of the State Survey Reports, from which the following data have been taken:

POTTSVILLE SERIES.

This formation consists of several beds of massive sandstone or conglomerate, separated by shales, and holding important coal beds, with a thickness of 150 to 2,000 feet. The series forms a continuous floor under the coal measures, forming the "salt sand" of the oil and gas drillers, coming to the surface along the borders of these measures. Dr. I. C. White gives the following description of these beds in volume II. (p. 611):

"The Pottsville series being composed mainly of very hard and often pebbly sandstones, the grains of which are cemented by silica and peroxide of iron, becomes almost indestructible by ordinary atmospheric agencies, and it has thus proved a most important factor in shaping the topography around the margins of the Carboniferous system. Wherever these beds come to the surface in West Virginia wild

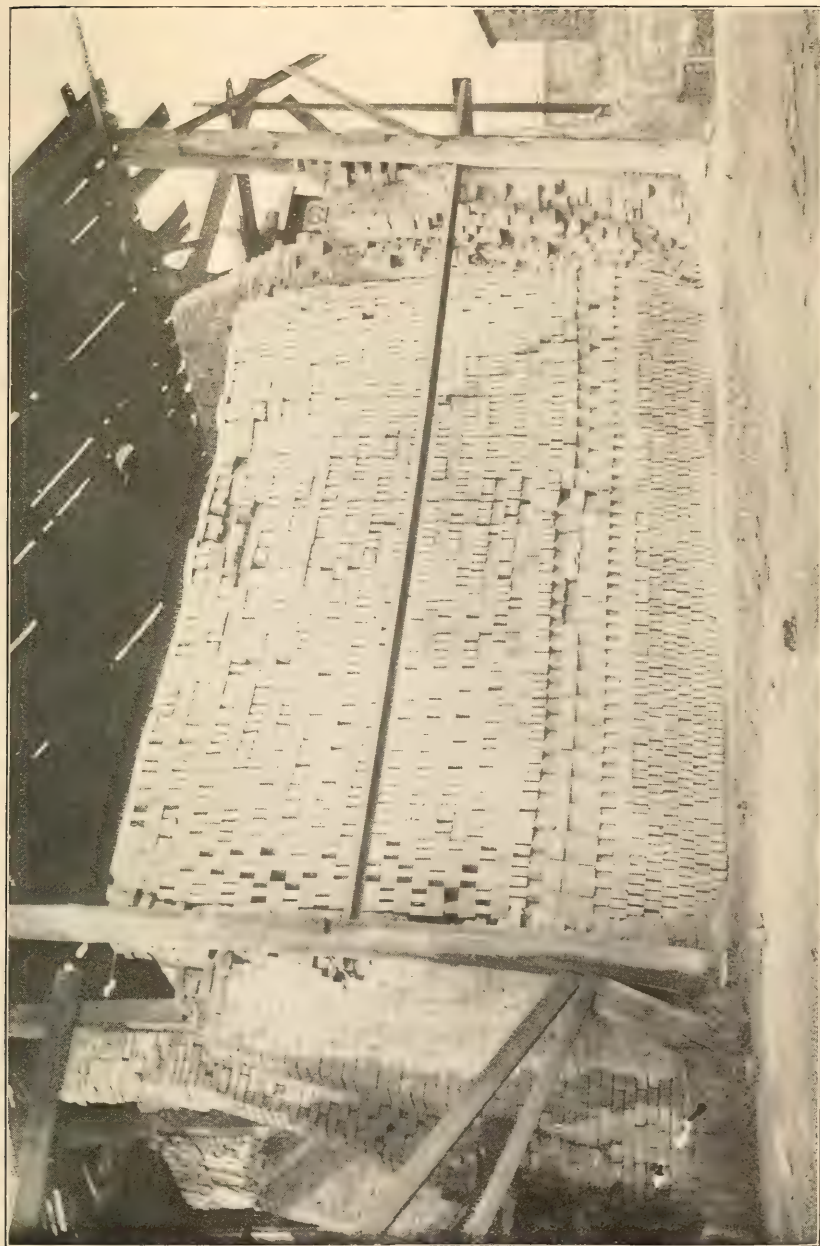


Plate XII.—Up Draft Type of Kiln and Brick, Clarksburg.

scenery and rugged topography are sure to be found. Rapid streams, high water falls, "rock cities," great cliffs, precipitous slopes, and barren regions generally mark the lines where these rocks emerge to daylight. The lofty peaks of the Allegheny mountains owe their origin to this friendly mantle, while its upturned edges have preserved many coal basins from complete erosion. The deep gorges, narrow canyons, and wild scenery of the Cheat, North Potomac, Tygart's Valley, Little and Big Kanawhas, Guyandot and Tug rivers are all carved from these rocks. The "Falls" of both Kanawhas, the Black Water and Stony rivers are over these rocks, as well as the "Roughs" of Tug and Guyandot. A belt of evergreen vegetation, laurel, hemlock, pines, etc., marks the soil (usually too poor, stony and infertile for agriculture) derived from this series."

The coals in this series form rather narrow belts, 25 to 30 miles wide around the southern border of the Appalachian field.¹ They are soft coking coals of high degree of purity.

In the northeastern part of the State the Pottsville series shows similar characters to that of Maryland and Pennsylvania. At the top is the Homewood sandstone, a coarse, often pebbly rock which reaches a thickness of 30 to 150 feet in Pennsylvania. Near Piedmont its thickness is 30 feet. A short distance below the Homewood sandstone is the Mt. Savage fire clay, mined in this State at Piedmont. In the Maryland section the Mt. Savage coal is over the clay, but appears to be absent at Piedmont, being replaced by clay.

The Mercer group includes two coals, the Upper Mercer under the Upper Mercer limestone, and the Lower Mercer under the Lower Mercer limestone. As this group is traced eastward from Mercer county, Pennsylvania, the limestones disappear, and the coals become thinner, one often disappearing. The Mercer coal has been mined near Valley Falls in Taylor county and appears along the North Potomac river, where it is known as the Railroad seam.

Below the Mercer group is a marked sandstone horizon named by White the Connoquenessing sandstone, lower and upper, 40 to 50 feet thick and usually quite hard. Between the two sandstones is the Quakertown coal seldom over two feet thick.

The Sharon coal is found in pockets and isolated basins reaching three and five feet in thickness in Mercer county, Pennsylvania, and through northeastern Ohio. The interval from the Sharon coal to the base of the Pottsville series in Ohio and west-

1. The facts in this section are taken from Dr. I. C. White, Bull. U. S. G. S., No. 65, pp. 199-205.

ern Pennsylvania is often occupied by a massive conglomerate known as the Sharon conglomerate. When this is absent, the coal with its clay rests directly on Lower Carboniferous beds.

In the southeastern part of the State the Pottsville coals are represented by the Sewell coal mined extensively in Fayette county; the Welch coal mined in McDowell; the Beckley mined in Raleigh, the Quinimont or Fire Creek in Fayette; the Horsepen coals of McDowell; and the four seams of Pocahontas coal, of which the No. 3, four to ten feet in thickness, is the most important seam in the Pottsville series, and ranks next to the Pittsburg seam in value. In West Virginia it is found only in the counties of Mercer, Raleigh, Wyoming, and McDowell, and more especially in the last county, where it covers an area of 500 square miles out of an entire area of 600 to 700 square miles.

ALLEGHENY SERIES.

This series "is capped at the top with the widely distributed, easily recognized, and valuable Upper Freeport coal bed, and extends down through several beds of fire clay, limestone, coal, shale, and sandstone, until a marked change in lithology takes place, the sandstones becoming harder, more massive, often very pebbly, and of a lithologic type quite different from the ordinary sandstones of the Allegheny series," forming the Pottsville series. The thickness of the Allegheny series is about 250 feet.

Clarion Coal.—At the base of this series is a coal vein called the Clarion, which at the north is 250 to 300 feet below the top of the series. In this area the coal is six to twelve feet thick with shale parting one to seven feet thick, giving five feet of coal. The coal often has a thick bed of fire clay under it which is not worked in this State.

Above the Clarion coal in Hancock county, along Cheat river in Preston and Monongalia and in Tucker, Grant, and Mineral counties, is found the *Clarion sandstone*.

Kittanning Group.—The Lower Kittanning coal is a very persistent coal through Ohio and Pennsylvania, but in West Virginia it is absent entirely as a workable bed in many regions of the State. It comes to the surface at Hammond and Valley Falls on the Tygarts Valley river with a thickness of five feet, but in places is cut out by the underlying fire clay. It is present near

New Cumberland, Hancock county, with a thickness of two to three feet, but in places is cut out by the overlying sandstone. It is mined at Corinth in Preston county, and at Coketon and Thomas in Tucker county, reaching nine to ten feet including the slate partings, and is locally called the "Davis" seam.

Under the coal is the Lower Kittanning fire clay mined at New Cumberland, five to fifteen feet thick, and at Hammond in eastern Marion county, where it is five to eight feet in thickness.

Between the Lower Kittanning and Upper Kittanning coals the interval is occupied by sandstone which becomes thick and massive along the Great Kanawha. About 20 to 30 feet above the Lower Kittanning in Pennsylvania and eastern Ohio is a good coal seam two to three feet thick, named the Middle Kittanning coal. It has been mined in this State near New Cumberland below the mouth of Holbert's run, and at mouth of King's creek. At Hammond it is 15 to 20 feet above the Lower Kittanning.

The Lower Freeport sandstone above the Kittanning coals in some places breaks into two portions separated by shales in which a coal vein called the Upper Kittanning coal sometimes appears. At the north it is two to three feet in thickness and worked in a few places for local use. It may be seen at Hammond and Valley Falls, also near Harrison and Piedmont in Mineral county. It outcrops at head of Buckhannon river, on Elk river, Wolf creek, and Birch river.

Lower Freeport Group.—Forty-five to seventy-five feet below the top of the Allegheny series is the Lower Freeport coal, which is locally called in Ohio and in the northern Panhandle the Rogers vein, where it is 120 to 130 feet above the Lower Kittanning coal and clay used in the large brick plants near New Cumberland. The coal passes under the Ohio river about two miles south of mouth of King's creek, and along this creek is locally known as the "Four-foot vein." Its thickness varies from two feet to four and one-third feet.

In Preston county it is called the "Three-foot" seam. Near Dellslow it is one foot thick and fifty feet below the Upper Freeport. It runs four to five feet near Bush in Taylor county. At Hammond in Marion county it is six feet thick, and about 140 feet above the fire clay used by the Hammond Brick Company.

In the basin of Tucker, Grant, and Mineral counties, this coal is only one to two feet thick and 40 to 60 feet below the Upper Freeport seam.

Below the Lower Freeport coal is the Lower Freeport Sandstone, hard and often pebbly. In Hancock county it is 75 to 100 feet in thickness, forming bluffs at New Cumberland, and is quarried on King's creek.

The stratum dips down to the east and is called by the drillers "Big Dunkard," "Second Cow Run Sand," etc. It comes to the surface again in eastern Monongalia and Marion counties. It is massive and pebbly between Grafton and Philippi, and near Moatsville unites with the overlying Roaring creek sandstone (Upper Freeport) to form a solid mass 100 feet thick. Near Junior the combined thickness reaches 200 feet. On many of the mountain streams, the "chimneys," "pinnacles," "turrets," are carved out of these beds, so that they are locally called the "chimney rocks." Along the Kanawha it forms with the overlying sandstone massive cliffs, cutting out the coal seams and extends beyond the Big Sandy river.

Upper Freeport Group.—At the top of the series is found one of the very important coals of the Appalachian field, the Upper Freeport, which forms a small basin in Mineral, Grant, and Tucker counties, also in northern Panhandle, and a larger area with thicker vein in a belt ten to thirty miles wide, extending across the State through Monongalia, Preston, Taylor, Barbour, Randolph, Upshur, Webster, Braxton, Clay, Nicholas, Fayette, Kanawha, Boone, Lincoln, Wyoming, Logan, and Mingo counties. It is a soft coking coal at the north with a thickness of six to nine feet, while at the south it reaches a thickness of twelve and fifteen feet and becomes harder or *splinty*.

Just below this coal comes the Bolivar fire clay, worked at a number of localities in Pennsylvania, but not as yet in this State. It has been opened near Dellslow on Deckers creek in Monongalia county, showing a good flint clay with several feet of soft plastic clay.

From five to twenty feet under the Upper Freeport coal, in Hancock, Preston, and eastern Monongalia counties, the Upper Freeport Limestone is found in several layers separated by shales and from ten to fifteen feet thick. A short distance below the Upper Freeport coal there is found over a wide area of the State,

a very massive and often pebbly sandstone, 50 to 75 feet in thickness, and near the mouth of Beaver creek in Randolph county, it unites with next underlying sandstone forming a mass 200 feet in thickness. It forms the falls of Roaring creek in Randolph county, and so is called *Roaring creek sandstone*. The stratum is generally quite pebbly and on this account is apt to be confused with the Pottsville.

KANAWHA SERIES.

In the southern part of the State is found the Kanawha series which is regarded by the West Virginia Geological Survey as including at least a part of the Allegheny series, and since the question is not settled beyond doubt, the two series will be considered separately in this review. For a full discussion of this subject the reader is referred to volume II. of this series of reports, from which the following facts are quoted:

In the Charleston section the heavy sandstones have been named by the U. S. Geological Survey the Charleston sandstone, which is probably equivalent to the Mahoning and Buffalo sandstones of the Conemaugh series. Two important coal seams are found in the section above the Kanawha black flint, known as the North Coalburg and the No. 5 block coal.

Kanawha Black Flint.—The black flint, well exposed near Charleston, is found through Kanawha, Fayette, Clay, and northern Nicholas counties. It was named by Rogers nearly seventy years ago, and has been used as a key rock in the study of the Kanawha coals since that time. In its typical form it is a compact bluish-black structureless flint weathering into small rectangular blocks. Below the black flint are found six coal beds which appear to be persistent over considerable areas.

Kanawha Coals.—The first coal bed below the Kanawha black flint is the Stockton coal found in Webster and Nicholas counties, and in Fayette and Kanawha splits up, often forming two distinct seams known as the Stockton and the Lewiston.

Eighty to ninety feet below the black flint is the Coalburg coal mined at Coalburg and other places in Kanawha county, five to six feet thick, held in high favor as a steam and domestic fuel coal. At 150 to 225 feet below the Kanawha black flint is the Winifrede coal mined near the town of Winifrede, Kanawha county, where its thickness is four to five feet.

Between the Winifrede and the next valuable coal seam, the Cedar Grove, there are 250 to 300 feet of sandy measures. The Cedar Grove coal was first mined near the village of Cedar Grove, Kanawha county, where it is about three feet thick. The coal is thought to cover a large area southwest from the Kanawha valley as well as northeast from it.

The Campbell's creek coal is found 410 to 640 feet below the Kanawha black flint and is the most important coal of the Kanawha series. The Campbell's creek limestone is thirty-four feet above the coal near the mouth of Campbell's creek and is rather persistent in the Kanawha valley though usually not over one foot in thickness. The Campbell's creek coal is generally known as a gas coal and is also a good coking coal. It is a multiple seam at the type locality and splits up and becomes more complex to the southeast along the Kanawha river, where the upper portion has been mined under the name of the Peerless seam, and the lower portion as the Blacksburg seam, each of which reaches five and six feet in thickness.

The Brownstown coal comes midway between the Campbell's creek and the Eagle coal below, but attains little economic importance. At seventy-five to one hundred feet below the Campbell's creek coal and forty-five to fifty feet above the Eagle coal is the Cannelton limestone, formerly burned into cement near Cannelton. The Eagle coal is 120 to 150 feet below the Campbell's creek coal first mined at Eagle, two miles from Montgomery. The coal makes excellent coke, and is a good steam coal. It is three to six feet in thickness.

Seventy-five feet below the Eagle coal is the Eagle limestone, locally called the "Black Marble" on account of its very dark color. In the Kanawha valley no other coal beds are visible in the 250 to 300 feet of shales and sandstones to the top of the Pottsville series.

CONEMAUGH SERIES.

Mahoning Group.—In some parts of the State the Upper Freeport coal is overlaid by a bed of sandstone called the Lower Mahoning sandstone. In other places the coal and sandstone are separated by 20 to 40 feet of dark, sandy, fossiliferous shale, called the Uffington Shales.

The Lower and Upper Mahoning sandstones sometimes form one solid ledge, 80 to 100 feet thick, hard, often pebbly, forming almost indestructible ledges. They are thus seen from Upshur southwest into Mingo, western Wyoming, and Raleigh counties. They form the steep bluffs along the Ohio river through Hancock county. This stone is quarried for building stone in a number of localities. The Upper Mahoning is generally the more massive member and the better quarry rock of the two. In the oil wells, this stratum is known as the "Dunkard" or "Cow Run" sand.

Between the two Mahoning sandstones there frequently occurs a coal bed known as the Mahoning coal, which is of economic importance in the hills near New Cumberland where it is five feet thick. The coal dips under the Ohio above Steubenville. It is found in southern Preston, eastern Barbour, western Randolph, eastern Upshur, and Lewis. Just under the coal and sometimes replacing it, is a good bed of fire clay in a few regions of the State, mined at Thornton. In a number of places a gray, impure limestone is found in the shale interval between the two Mahoning sandstones.

Cambridge Limestones.—This limestone occurs in two strata separated by the Buffalo sandstone. The Upper Cambridge limestone forms one of the important guides in the identification of the series. It is seen through Brooke and Hancock counties, near Morgantown, and from this point to Grafton along the Monongahela and Tygarts Valley rivers.

The Lower Cambridge limestone is found 60 to 95 feet below the Upper limestone, but is usually concealed by debris from the overlying sandstone. Both limestones are very fossiliferous and dark colored. They are separated by the *Buffalo sandstone*, which forms the cliffs 50 to 100 feet above the railroad at Grafton where it has been quarried. It is exposed at Morgantown, forms the cliffs half way up the hills at Philippi, and is quarried two miles south of Buckhannon. It occurs near Sutton and on down to Charleston and forms the top of the bluffs at the mouth of Elk river. It passes southwestward leaving the State in Wayne county.

Ames Limestone.—At 90 to 120 feet above the Upper Cambridge limestone is a fossiliferous limestone with constant characters of wide distribution forming another important guide rock

and called the Ames or Crinoidal limestone. It outcrops one to ten feet in thickness in the northern part of the State and south into Lewis county, and again near Huntington and below Charleston.

Between the Ames and Cambridge limestones there is a mass of *Pittsburg Red Shales*, 30 to 100 feet thick which extend from Pennsylvania line south to the Big Sandy river. These red shales forming a conspicuous feature in the topography of this portion of the State are as yet only used in the Huntington Roofing Tile plant.

These shales are partly replaced by the *Salzburg Sandstone* in Preston county near Reedsville, Masontown, and Kingwood, also near Collier and Wellsburg in Brooke county.

At an interval of 60 to 100 feet below the Ames limestone is often found the *Bakerstown* or *Barton coal*, three to four feet thick mined near Colliers in Brooke county, also in Preston county, and between Grafton and Philippi, and other sections.

Morgantown Sandstone.—About 200 feet below the Pittsburg coal is a heavy stratum of sandstone named the Morgantown sandstone, which can be traced southwest across the State from Monongalia county through Wayne and Cabell into Kentucky. It is 25 feet in thickness at the north and near Huntington forms cliffs 60 feet in height. While used as building stone, it does not withstand exposure successfully.

Just under this sandstone is the *Elk Lick coal*, three or four feet in thickness, and found through the same belt as the sandstone. In places the *Elk Lick limestone* is found just below the coal. The remaining interval to the Ames limestone is occupied by the *Birmingham shale*.

Connellsville Sandstone.—This sandstone is one of the best building stones in the whole series. It has been quarried near Mt. Clare and Clarksburg in Harrison county and outcrops between Morgantown and Fairmont, with a number of quarries opened in it. As a pebbly sandstone it caps the summits and forms almost level plateaus in the Potomac basin southwest of Elk Garden in Mineral county.

Just under the Connellsville sandstone is a very persistent coal bed, the *Little Clarksburg coal*. It is often double with two or three feet of slate parting. The coal is coarse and bony and of

little value. Below the coal is the *Clarksburg limestone*, twenty to thirty feet in thickness. It is found especially in the northern portion of the State and has been used for lime and for road material.

In the 100 feet of measures at the top of the Conemaugh two well marked limestones are found, one five to six feet thick, and 25 to 35 feet below the Pittsburg coal, the other eight to ten feet thick and 50 to 60 feet lower. These are called the *Upper* and *Lower Pittsburg limestones*.

The Conemaugh series extending from the floor of the Pittsburg coal down to the top of the Upper Freeport coal has an average thickness of 600 feet.

MONONGAHELA SERIES.

This series extends from the Pittsburg coal up to the Cassville shale, with a thickness varying from 260 feet along the Ohio river to 400 feet in the central portion of the Appalachian basin. It contains six distinct coal beds: Waynesburg, Little Waynesburg, Uniontown, Sewickley, Redstone, and Pittsburg.

Dr. I. C. White in volume II. gives the following description of the rocks of this series:

"In the northern part of the State nearly one-half of the rock material composing the Monongahela series is limestone, red shales are unknown, while massive sandstones are seldom found except along the eastern side of the Monongahela outcrop. The disintegration of these limestones, limy shales, and other soft rocks at the north gives origin to a gentle topography and an extremely fertile soil, thus forming in Monongalia, Marion, Harrison, Lewis, Marshall, Ohio, and Brooke counties, as well as in portions of Upshur, Barbour and Taylor the finest agricultural and grazing regions in the State.

"In passing southwest from Harrison, Taylor, and Lewis counties, however, the limestones practically disappear, along with most all the coal beds, while red shales come in as the limestones go out, apparently replacing the latter, and the sandstones grow more massive than in the northern area, thus giving origin to a rugged topography and less fertile soils.

"These rocks extend over a wide area along the Ohio river and for many miles south of it, as far as the Great Kanawha, and in a narrow belt from that point to the Big Sandy where in the center of the Appalachian trough, the lowest of these beds passes into the air before reaching the Kentucky line."

The order of the rocks in the Monongahela series is shown in the outline at the beginning of this geological discussion, and reference will be made here only to the lowest but most important member.

Pittsburg Coal.—This vein of coal extends from Pittsburg, Pennsylvania, in an unbroken sheet 200 miles up the Monongahela river. The area of workable coal in this vein in Pennsylvania, Ohio, West Virginia, and Maryland is about 6,000 square miles, and six and one-half feet in thickness.

It is mined in good thickness through Monongalia, Marion, Harrison and Taylor counties. It is mined in the tops of the hills near Buckhannon in Upshur county, near Weston and other places in Lewis county, and thins out in Gilmer. It is mined in some of the high knobs of Braxton county, also in northern Clay, in southern Roane and Putnam in isolated patches.

From Point Pleasant northward along the Ohio river this coal is thin until at Spilman, where it is mined with a thickness of four to about six feet. It is mined at Mason City, Hartford, Moundsville, Wheeling, and Wellsburg. There once was a deposit of 600 acres near Elk Garden, Mineral county, now nearly worked out. The coal is seen in the tops of the hills near Huntington and is mined near Ashton, Mason county, and also at Raymond City and along Two Mile creek near Charleston.

DUNKARD SERIES OR PERMO-CARBONIFEROUS.

The Dunkard series includes all of the beds above the Waynesburg coal of the Monongahela series, and completes the succession of formations in this State. The dividing line is drawn where Permian plants have first been observed in the fossil flora. The maximum thickness of the series preserved is about 1,200 feet. The rock strata of this series are given with their names in the outline at the beginning of this geological review.

“Erosion has completely removed these rocks from several thousands of square miles in the State where they once doubtless existed, and also has very probably reduced their total thickness by many thousands of feet.

“As exhibited in West Virginia, the rocks of this series consist of a succession of brown and gray sandstones, interstratified with much red shale, many beds of limestone, and several thin, impure, and unimportant coal beds, the entire series being slightly gypsiferous throughout.

Passing south-westward, the coal beds all disappear except one (the Washington) before reaching the Little Kanawha river, and the limestones with one or two exceptions thin away into great masses of marly red shales holding only nuggets of lime, while the sandstones thicken up, and capping the ridges in long lines of cliffs, often make a rugged topography better fitted for grazing and fruit culture than

for agriculture. When the massive sandstones disappear from ridges or uplands, however, there frequently occur limited areas of beautiful rolling lands which yield abundant crops, the red marly shales being quite fertile from the disseminated limestone nuggets.

"These rocks occupy a belt about 40 to 60 miles in width bordering the Ohio river, and extending east from the same over portions or all of the following named counties: Ohio, Marshall, Wetzel, Tyler, Monongalia, and Marion (west of the Monongahela river), western Harrison, and Lewis, Doddridge, Pleasants, Wood, Wirt, Ritchie, Calhoun, Gilmer, Roane, Jackson, and the uplands of Mason and southern Putnam, but tailing out into the narrow belt, which soon overshoots even the highest hills of Wayne, a short distance east from the Big Sandy river at the Kentucky boundary."—Dr. I. C. White, W. Va. Geological Survey, Vol. II., p. 101.

CHAPTER VIII.

DESCRIPTION OF THE WEST VIRGINIA CLAY INDUSTRY, AND THE GEOLOGICAL HORIZONS OF THE BEDS.

The State of West Virginia is well supplied with valuable clay deposits, which are found in all sections of the State and at nearly all geological horizons, but at the present time only a small proportion of these are utilized.

The clay industry of the State has a promising future outlook, and when the important undeveloped deposits become known and carefully considered in connection with the excellent railroad and water transportation facilities, and the short distances by these routes to large cities, the industry is bound to increase and develop into one of the very prominent sources of wealth to the State and its citizens.

In this chapter will be given a description of the clay deposits and clay industries of the State arranged for convenience according to the geological horizons, beginning with the lowest now developed, the Silurian. The list of valuable clays which are not yet utilized is by no means complete, but includes only deposits which were examined in visiting sections where clay industries are already established. At a future time it is hoped that a complete description may be given for the clay deposits of this State in all the counties. The present report is therefore to be considered as a preliminary one, intended to give to the public such information as has been collected bearing on this important subject.

The following clays will be described in this chapter :

SILURIAN.

Bakerton.
Charles Town.
Shepherdstown.
Martinsburg.

DEVONIAN.

Elkins.

LOWER CARBONIFEROUS.

Cheat river.

Hendricks.

UPPER CARBONIFEROUS.*POTTSVILLE SERIES.*

Piedmont.

ALLEGHENY SERIES.

New Cumberland.

Hammond.

Decker's creek.

CONEMAUGH SERIES.

Thornton.

Junior.

Charleston.

Barlow.

Morgantown.

Huntington.

Barboursville.

Ona.

Clarksburg (Monticello).

MONONGAHELA SERIES.

Clarksburg.

Spillman.

Moundsville.

DUNKARD SERIES.

Parkersburg.

SILURIAN CLAYS.

The basal member of the Silurian in this State is the Shenandoah limestone which covers a large area in Berkeley, Jefferson, and parts of Hardy, Hampshire, and Pendleton counties.

The limestone strata in these areas are much folded, but not changed or metamorphosed into marble. The surface of the country is a rolling plain cut through the tops of the up and down folds known as anticlines and synclines, so that the rocks found at the surface pitch downward often at high angles. It is impossible to measure their thickness, but this is probably 2,000 to 4,000 feet. The upper portion of this massive limestone is Lower Silurian in age as shown by its preserved fossil remains, while the lower portion contains Cambrian fossils. The central layers are almost or quite non-fossiliferous, so that the line be-

tween the Cambrian and Silurian cannot be drawn. The limestone varies in color from nearly pure white to drab and blue.

The surface is usually covered by a red clay soil, five to thirty feet in depth. The limestone at Charles Town, Jefferson county, and at Bakerton, 14 miles distant, have the following composition :

	Charles Town Bakerton.	
Lime carbonate (CaCO_3).....	80.69	95.55
Magnesia carbonate (MgCO_3).....	7.48	2.44
Silica (SiO_2).....	5.21	0.12
Iron and alumina (Fe_2O_3 and Al_2O_3).....	3.90	1.01
Sulphur (SO_3).....	0.22	0.15
Phosphorus (P_2O_5).....	0.12	0.02

The limestone thus varies in its chemical composition in different parts of the area, and becomes high in magnesia, forming a dolomite at Millville. Over a large portion of the area it is a very high grade limestone and an important source of lime.

The red clay is found over the limestone wherever the latter outcrops and is formed in part from the limestone and from transportation of other materials by water. Its percentage of lime is quite low, while the percentage of silica is very high, showing that it has not been formed entirely by the weathering of the limestone. It agrees in chemical composition more closely with the shale or slate found in the limestone belt. The deposit of this clay over the limestone at Bakerton is ten to twenty-five feet in thickness and shows the following components :

	Bakerton. Charles Town.	
Silica (SiO_2).....	55.43	54.35
Alumina (Al_2O_3).....	18.78	21.49
Ferric iron (Fe_2O_3).....	7.06	8.00
Ferrous iron (FeO).....	0.15	0.00
Magnesia (MgO).....	2.59	0.79
Lime (CaO).....	1.56	0.30
Soda (Na_2O).....	0.12	Trace.
Potash (K_2O).....	0.69	6.35
Water (H_2O).....	2.62	1.62
Titanium (TiO_2).....	0.60	0.86
Phosphorus (P_2O_5).....	0.60	0.09
Sulphur (SO_3).....	1.05	Trace.
Loss on ignition.....	9.13	5.70
	100.38	99.55

By comparing this analysis with one from the Martinsburg shale in the next section of this chapter, the close resemblance in composition is seen. The clay has a bright red color due to the high percentage of ferric iron (7.06). It has a low percentage of lime and burns into a brick of good red color, but of loose, open

texture, and often quite brittle, due in large part to the method of burning without proper care in controlling the temperature of the kilns. It vitrifies at cone 5 (2246° F.)

Charles Town, Jefferson County.

Brick plants using this red clay have not been very successful in the Charles Town region, though farther north at Shepherdstown a very fair grade of building brick is made from the red clay.

Jefferson Cooperage Company.—This company operated a small plant during a part of the season of 1903, one mile north of town at the side of the Norfolk & Western railroad. They used a vertical wooden pug mill box and a soft mud machine, both operated by horse power. The brick were dried in the open yard and burned in two small temporary scove kilns. 330,000 brick were made, but the product not being satisfactory, the works have been abandoned.

The Getzendaner yard located one mile southeast of town was operated in a small way for a number of years on the same kind of clay, but it has been abandoned for the past five or six seasons.

Charles Town Brick and Tile Works.—This plant is located north of town near the Jefferson plant and was in operation for some eight or ten years, but has been idle for two seasons. The yard is equipped with a "chief" soft-mud machine, consisting of a vertical press box three feet in diameter, with a horizontal twelve-foot pug mill, operated by horse power. The clay is tempered in a ring pit and pug mill. The brick were molded partly by hand and partly by machinery, and burned in scove kilns.

The red clay in these yards is two to four feet deep resting on the limestone, and with large limestone boulders scattered through it. While the clay is of shallow depth, the acreage is large as it is found in all of the small valleys in this section. The analysis of the clay taken from the pit of the Jefferson Cooperage Company shows very little difference from that at Bakerton, as given above. These clays have very constant characters wherever found, and hence have been derived from the same source.

Physical Properties.—This clay slakes in one minute and requires 32 per cent of water to develop its normal molding consistency, the maximum plasticity is 19 (see chapter III.) Its air

shrinkage is 8 per cent, and tensile strength reaches 153 and 167 pounds to the square inch. The strength was not injured by rapid drying. Its specific gravity is 2.61. It vitrifies at cone 1 (2102° F.), and becomes viscous at cone 5 (2246° F.) All of these tests justify the conclusion that if these clays were properly worked they should make a good grade of common building brick.

Mechanical Analysis.—By mechanical analysis as explained in chapter II., this clay gives the following results:

	Range in millimeters.	Per cent.
Fine clay	0.0 to .001	37.7
Coarse clay	.001 to .005	14.2
Silt	.005 to .02+	29.7
Fine sand	.02 to .15+	12.1
Coarse sand	.15 to .3	4.7
Water		1.6

The brick were loosely molded and burned in temporary kilns, sometimes without proper drying. No special attention was paid to regulating the time of burning or temperature of the kilns, and the resulting product was of inferior quality, much of it unsalable. The clay is not adapted to the manufacture of high class brick, but with care should make a very fair grade of building brick for local use and for nearby towns. During the past season while these brick remained at the yard unsold, brick made from similar clay was shipped into Charles Town by the car load to supply the local demand.

Shepherdstown, Jefferson County.

The Henson brick yard is located at the west edge of Shepherdstown, and uses a clay similar to that in the southern part of the county at Charles Town. The plant was started six years ago and has been very successful in the manufacture of common building brick, its product being seen in the State Normal School building in the town. The clay is tempered in a soak pit and moulded in a Martin soft-mud machine of 12,000 daily capacity, though the average daily production of the yard is only 7,000. The brick are dried in five shed pallet driers piled ten pallets high. These driers hold 12,500 brick. A roof storage shed is used for the dried brick until time to fill the kiln. The brick are burned with coal six to seven days in an up-draft permanent clamp kiln with eight arches, holding 140,000 brick. Last season 420,000 brick were made at this yard.

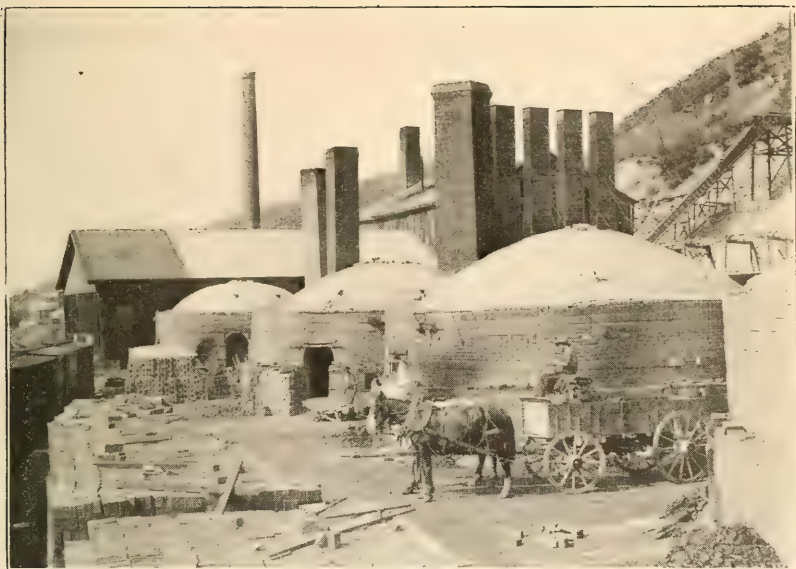


Plate XIII-a.—Down Draft Brick Kiln, Crescent Yard, New Cumberland.



Plate XIII-b.—Clifton Sewer Pipe Yard, New Cumberland.

The red clay is four to five feet deep, resting on the limestone. The surface of the stone is very irregular through erosion, and in crevices of the rock the clay extends to considerable depth. The well at the yard was dug 32 feet in clay to the limestone.

The chemical composition of these red clays, with the high percentage of silica, their location in depressions of the surface and along the stream valleys, and the eroded irregular surface of the limestone floor, would indicate that the deposits were transported, allied in origin to the river clays of other portions of the State described in the last section of this chapter.

Martinsburg, Berkeley County.

The next higher division of the Silurian in the State, the Martinsburg shale, is found typically displayed in the neighborhood of Martinsburg, and covers a very considerable area. The shale or slate, as it is locally called, occurs in synclinal folds or basins in the Shenandoah limestone, probably 600 to 2,000 feet thick. The shales are brown to black in color, micaceous and with cleavage often well developed. The slate is quarried at one point for structural purposes, but its use as roofing material is as yet a doubtful proposition.

At the surface the shale weathers forming a brownish soil which is not very deep but of fair degree of fertility. The hard shales are not used for brick, but the weathered outcrop appears to be well adapted to this industry, though at the present time there is but one plant using the Martinsburg shale.

Buxton Brick Works.—This plant is located one-half mile northeast of the city of Martinsburg, and was built in 1895. The shales are ground in a nine-foot dry pan, tempered in a horizontal wooden twelve-foot pug mill, and molded in a stiff-mud auger machine with a daily capacity of 30,000 brick which are side cut.

The brick are dried in six dry sheds made with double sloping roof set on poles, with open sides holding 38,000 to 45,000 each. One shed is enclosed and provided with steam pipes in the floor, for use in bad weather. The brick are burned seven to eight days with coal fuel in two up-draft ten-arch permanent wall kilns holding 206,000 and 212,000 brick. The brick are red in color, uniform in texture, hard and strong, and they are in good demand for local trade.

The shale is worked in an open pit, three to eight feet deep, borings sixteen feet deep show the shale continuing at that depth. Only the softer, weathered portions are used and masses of harder shale are left in the pit, the softer shales being worked around them. The cleavage planes run in different directions, giving a broken appearance to the bank. Pure white clay streaks a few inches thick occur all through the shale, but are common in the upper four feet. The shale comes to the surface of the field in many places, while in other parts it is covered by four to eight inches of soil. The chemical composition of the unaltered shale (slate) and the weathered shale in the Buxton pit are shown by the following analyses:

	Lovett Quarry. 60 feet deep. Buxton Yard.	
Silica (SiO_2)	53.30	57.75
Alumina (Al_2O_3)	18.16	20.17
Ferric iron (Fe_2O_3)	1.95	7.00
Ferrous iron (FeO)	4.58	0.33
Magnesia (MgO)	2.65	1.22
Lime (CaO)	4.89	0.22
Soda (Na_2O)	0.82	0.62
Potash (K_2O)	3.70	2.59
Water (H_2O)	0.68	2.75
Titanium (TiO_2)	0.72	0.87
Phosphorus (P_2O_5)	0.24	0.09
Sulphur (SO_2)	0.77	0.00
Loss on ignition	7.36	5.94
	99.82	99.55

Physical Properties.—The clay does not slake readily, requiring a long time. It takes 28 per cent of water to develop its normal molding consistency, the maximum plasticity being 20. Its air shrinkage is 4 per cent, and the clay attains a tensile strength of 122 pounds to the square inch. Where the clay is well weathered this strength reaches 150 pounds, and it is but little decreased by rapid drying. The clay vitrifies at cone 1 (2102° F.) with fire shrinkage of 11 per cent, and is completely vitrified at cone 5 (2246° F.)

Clinton and Medina Shales.—The red shales of the Medina and the brown and gray shales of the Clinton are found in belts along the mountain slopes through Mineral, Grant, Hardy, and Pendleton counties. They are located in districts where there would be little or no demand for brick and have not been utilized or even tested.

DEVONIAN.

The Devonian formations of West Virginia have not been as yet carefully studied, but they consist of sandstones and shales. These are found through Mineral, Grant, Hardy, Pendleton, Preston, Tucker, Randolph, Pocahontas, Greenbrier, and Monroe counties. These shales are grouped under the Hamilton, Chemung, and Catskill formations whose combined thickness is estimated at 5,000 to 6,000 feet. Many of these shale deposits are adapted to brick manufacture. They might be worked at a number of places, but at the present time are used only at Elkins.

Elkins, Randolph County.

Elkins Brick Company.—The plant of this company is located a little over a mile south of town on the West Virginia Central railroad, and was started in 1901, using Hamilton shales. The shale is ground in two nine-foot dry pans, tempered in a twelve-foot pug mill, and molded in a Bucyrus auger stiff-mud machine (Giant No. 2) with a capacity of 60,000 brick a day. The average production of the yard is 25,000 brick.

The brick are dried in a seven-track steam tunnel drier, each track holding ten cars with 500 brick to the car, giving a total capacity of 35,000. The building brick are burned in two up-draft kilns built with twenty-eight arches and permanent walls holding 180,000 each. The paving brick are burned in six down-draft kilns, twenty-eight feet in diameter, which draw into one stack and hold 68,000 brick each. The company made 4,000,000 brick in 1904. The brick are of good red color, dense and strong, being popular for buildings and street pavements. The brick are burned with natural gas, and the machinery is housed in a good substantial frame building.

The shale pit is back of the mill a short distance and is worked by a long narrow cut with the track in center. A thickness of forty feet of blue shale weathering buff is exposed, the bottom of the deposit not yet being found in wells. There are two feet of soil cover, then four feet of buff weathered shale, with the rest of bank blue shale. Ten feet from the bottom is an eight-inch streak of sandstone. The present opening runs north and south about 500 feet long. The same shale is exposed in a twenty-foot cut on the railroad to the east of the plant, and it ex-

tends over a large area to the west. At the north end of the pit the hill descends abruptly 60 to 75 feet to the broad valley of the river with its alluvial soil. The layers are almost vertical with a dip to the northeast and they are for the most part regular and unbroken, but in places are very much crumpled.

A chemical analysis of this shale gives the following:

Silica (SiO_2)	58.78
Alumina (Al_2O_3)	22.57
Ferric iron (Fe_2O_3)	4.13
Ferrous iron (FeO)	1.40
Magnesia (MgO)	1.00
Lime (CaO)	0.18
Soda (Na_2O)	0.54
Potash (K_2O)	3.15
Water (H_2O)	1.05
Titanium (TiO_2)	1.03
Phosphorus (P_2O_5)	0.35
Loss on ignition	5.43
	99.61

Physical Properties.—The shale slakes very slowly and requires 25 per cent of water to develop its normal molding consistency; the maximum plasticity being 15. Its air shrinkage is three and one-half per cent, and it dries very slowly. The tensile strength is low, 34 to 40 pounds, and if rapidly dried only reaches 10 pounds. The weathered buff shale reaches 83 pounds tensile strength.

It vitrifies at cone 1 (2102° F.), with fire shrinkage of 10 per cent, and is red in color. At cone 5 (2246° F.), it becomes black, but not viscous. This shale is greatly improved by weathering and it would be profitable to break down larger masses and leave them exposed to the action of the weather, aided by watering from time to time.

LOWER CARBONIFEROUS.

Mauch Chunk Shales.—This division consists of red and grayish-blue shales, green sandstones, and a few thin limestones, with a thickness at the north along Cheat river of 300 feet, increasing at the south on New river to 2,000 feet. The belt extends across the State from Preston county through Tucker, Randolph, Pocahontas, Greenbrier, Monroe and Summers counties.

The red shales especially, and the clays resulting from their weathering, would in many places make a good quality of red

brick, and would be adapted to the manufacture of a beautiful pressed brick. The quantity of material is almost unlimited and occurs convenient to railroads and close to valuable fuel deposits. Up to the present time they have not been used at any place within the State.

At the north on Cheat river, the shales and clay resulting through weathering have the following percentages according to analyses made by R. L. Humphrey:

	Shale. Per cent.	Clay. Per cent.
Silica	62.14	68.16
Alumina	19.40	16.18
Iron		
Lime carbonate	0.38	0.42
Magnesia carbonate	1.41	1.04

Further south in Tucker county the shale and clay have the following composition as determined by George P. Maury:

	Shale. Per cent.	Clay. Per cent.
Silica	57.88	67.10
Alumina	15.80	18.74
Iron	4.81	5.14
Lime carbonate	16.86	0.96
Magnesia carbonate	2.08	0.96
Water	2.72	4.69
Alkalies .....	.....	2.40
	100.15	99.99

The Mauch Chunk red shales on Decker's creek a few miles from Morgantown, have the following composition:

	Per cent.
Silica	56.30
Alumina	19.07
Iron	9.58
Magnesia oxide	2.01
Lime oxide	0.69
Water and loss on ignition	8.01
Titanium	0.71

CARBONIFEROUS.

POTTSVILLE SERIES.

The Pottsville series contains clays, shales, sandstones, conglomerates, and coal veins. The only clay material so far utilized is a bed of fire clay which comes below the Homewood sandstone at the top of the series, and which is called the Mount Savage fire

clay from the locality in Allegheny county, Maryland, where it has long been mined and used.

Piedmont, Mineral County.

In the hills near Piedmont the section includes the rocks from the Mauch Chunk shales up through the Pottsville, Allegheny and Conemaugh series, and far into the Monongahela.

The following section was made of the hill at Piedmont Brick Works and agrees closely with the one across the river at Westernport given by Dr. White in Bulletin 65 of the U. S. G. S.:

	Feet.	Inches.
Upper Freeport coal	4	..
Concealed	25	..
Lower Freeport coal	2	..
Sandy shales, sandstone and concealed.....	135	..
Lower Kittanning coal	6	..
Shales and concealed	65	..
Sandstone, shaly	25	..
Sandy shales, and concealed.....	35	..
Coal, Clarion	1	6
Shales	3	..
Limestone, nodular	5	..
Sandy shales and concealed	35	..
Sandstone, Homewood	30	..
Black shale	3	..
Flint clay, Mt. Savage.....	7	..
Plastic clay, Mt. Savage.....	7	..
Sandstone	3	..
Shales and concealed.....	65	..
Sandstone	15	..

Piedmont Brick and Coal Company.—The plant of this company is the only one using the Mount Savage clay in this State. The brick works are located one mile east of the town of Piedmont on the Baltimore & Ohio railroad.

The clays are ground in a nine-foot dry pan, tempered in a twelve-foot pug mill and molded in a Raymond stiff-mud auger machine with a capacity of 30,000 brick daily. The brick are repressed in a Victor two-mold machine, and dried in a Sharer hot air tunnel drier containing five tracks with a capacity of 45,000 brick. The machinery is housed in a substantial frame building with a large storage shed at the side for finished product which can be loaded at the level of the car floor. The company manufactures building, paving, and fire brick. The brick are burned with coal in four down-draft circular kilns, thirty feet in diameter, which draw into one stack and hold 80,000 each.

The clay mine is located on the hill back of the plant, and 180 feet higher. A track one-fourth mile long leads from the mine around the hill to the top of the incline above the mill. The clay has been worked only a short distance into the hill by open pits except in two places where shallow entries have been made under the hill.

On the outside in the open pits, the fire clay comes above a thin vein of coal and has at base three feet of soft or plastic fire clay nearly black in color, but becomes bluish white as it is traced into the hill in the entries. Above are eleven or twelve feet of clay made up of a mixture of soft clay and flint clay ledges in the weathered portion of the hill. In the entries three feet of flint clay are exposed above the plastic clay, but the workings do not reach the top of the vein. As near as can be determined there are seven feet of plastic clay overlaid by seven or eight feet of flint clay with a heavy sandstone roof (Homewood sandstone).

The plastic clay in the outer openings is laminated and irregularly broken with flint clay nodules through it. These nodules vary in size from coarse gravel to three feet in diameter, being round, with smooth surfaces stained with iron films. The clay dips north so that the mines operated from that side of the hill have to work on an incline from the mouth of the entry, making extra trouble in removing the clay and water from the mines.

The following analyses were made of the dark plastic clay occurring on the outside of the mine entry and the whiter plastic clay on the inside:

	Outside.	Inside.
Silica	45.25	51.34
Alumina	33.45	29.75
Ferric iron	1.79	1.65
Ferrous iron	0.98	2.07
Magnesia	0.39	0.49
Lime	0.17	0.31
Sodium	0.41	0.18
Potassium	2.21	1.45
Water	1.52	0.98
Titanium	1.60	2.13
Phosphorus	0.14	0.07
Loss on ignition	11.67	10.22
	99.58	100.64

These analyses show very little chemical difference, though there is such a marked difference in color. The percentage of titanium in the whiter clay is the highest determined in any of

the clays in this State thus far examined, and this percentage in the darker clay is only exceeded by the fire clay at Hammond. The fusible components of these clays amount to 5.95 and 6.15 per cent., being much higher than in the flint clay. The iron percentage is low and the brick burn a buff color.

The flint clay gives the following composition as compared with the Maryland Geological Survey analysis from Mt. Savage:¹

	Piedmont.	Mt. Savage.
Silica	61.44	56.147
Alumina	26.18	33.295
Ferric iron	0.30	0.59
Ferrous iron	0.36	.....
Magnesia .....	.....	0.115
Lime	0.12	0.17
Sodium	0.02	.....
Potassium	0.00	.....
Water	0.77	9.68
Titanium	1.39	.....
Phosphorus	0.01	.....
Loss on ignition	9.07	.....
	99.66	99.997

The Piedmont flint clay only contains 0.80 per cent of fluxes, which is the lowest found in any clay in the State, and which is a little lower than that of the Mount Savage clay, 0.875 per cent. The percentage of silica and alumina is 87.62 as compared with 89.44 per cent in the Mount Savage clay.

Physical Properties.—This clay requires 21 per cent of water to give a good working consistency; its maximum plasticity is 4; air shrinkage, 3 per cent; the tensile strength is 32. The clay shows very little change at cone 30 (3146° F.) and burns light color.

The coal used for burning the brick is mined from a six-foot vein (Lower Kittanning), 260 feet above the clay deposit.

ALLEGHENY SERIES.

The Allegheny series includes some very important coal seams, with underlying fire clays, which are found in a number of localities in this State. The two important groups are the Kittanning coals and clays, and the Freeport group of coals, clays, and sandstones.

Two especially valuable fire clay beds occur, one just below the Kittanning coals, and the Bolivar fire clay below the Upper

1. Maryland Geol. Survey, Vol. IV., p. 451 (Ries).

Freeport coal. The shales in the series have been used with good success at New Cumberland in the manufacture of building brick.

KITTANNING CLAYS.

New Cumberland, Hancock County.

The largest brick manufacturing center in the State is around New Cumberland, where the Middle and Lower Kittanning clays are used for the manufacture of building brick and paving blocks, and the Lower Kittanning clays for sewer pipe. The shales between these clays were formerly burned into common brick.

The town of New Cumberland was not established until 1839, but clay was shipped from this section, at mouth of Holberts run, in 1830 and taken to Pittsburg, where it was used for brick manufacture. Two years later the first brick plant was erected. In the next twelve years five plants were in operation. The output increased from 200,000 brick in 1837 to 1,500,000 in 1844, and 11,00,000 in 1872, in addition to 12,000 tons of fire clay shipped to points on the Ohio river. The first gas well was struck in this section in 1862 and in 1876 was used for burning brick at the Clifton plant. This is probably the earliest date that gas fuel was used in brick works.

Standard Fire Brick Company.—The original plant of this Pittsburg company was erected by David Troup in 1874, and is located at the side of the Pennsylvania railroad track two and one-half miles north of the New Cumberland station, at a point called Globe.

The clay from the bank above the mill is broken in a Blake crusher and then finely ground in two nine-foot Stevenson dry pans, tempered in a twelve-foot pug mill and molded in a Bonnot stiff-mud auger machine with a capacity of 60,000 brick a day.

The brick are dried in an eight-track hot air tunnel drier, which has a capacity of 55,000, and burned with coal in seven 28-foot and four 30-foot kilns, holding 55,000 and 60,000 brick. The brick are buff in color. This plant also grinds 200 to 300 tons of clay a month, and ships the product to the steel works at Pittsburg.

Rocky Side Brick Plant.—This plant was built by Evans & Shane in 1870 and is now owned, with a number of other plants

below, by the Mack Manufacturing Company of Philadelphia, which bought the property and formed the consolidation of these plants in January, 1894. The plant is one-half mile below the Globe works of the Standard Fire Brick Company. The clay is brought from the mines above the plant, ground in three nine-foot dry pans, tempered in pug mill, and molded in a Freese auger machine with capacity of 60,000 brick in ten hours.

The brick are dried in a nine-track tunnel drier and burned in ten Eu Daly down-draft kilns and two round down-draft kilns, 28 feet in diameter, holding 34,000 paving blocks or 62,000 standard size brick. The brick are buff colored, made $8\frac{3}{8} \times 4 \times 2\frac{1}{2}$ inches for standard size brick, and $9\frac{1}{4} \times 3\frac{1}{8} \times 4$ inches in the blocks which weigh $9\frac{1}{4}$ pounds. On demand the brick are repressed on a Richardson machine.

Union Brick Plant of Mack Company.—The Union plant is located about one-quarter mile below the last, and was started in 1868 by Thomas Manypenny. The equipment is similar to that in the Rocky Side plant. There are seven Eu Daly kilns and four of home construction.

Eagle Sewer Pipe Plant of Mack Company.—The Eagle plant is about 1,000 feet below the Union, and was started as a brick plant in 1870 by Manypenny and Cuppy.

The clay used was from the Lower Kittanning bed mined close to the plant. It was crushed in a nine-foot dry pan and same size wet pan, and molded in a Turner, Vaughn & Taylor press with 44-inch steam cylinder and 20-inch clay cylinder capable of making pipe from two to twenty-four inches in diameter. The pipe were dried on three slat floors, one above the other, heated by steam, and burned in eleven circular down-draft kilns, 28 and 30 feet in diameter. The plant has not been operated since 1902.

Aetna Brick Plant of Mack Company.—The Aetna plant is 1,200 feet below the Eagle works and is one of the oldest plants in the State. It was started in 1844 by Thomas Freeman. There are two nine-foot dry pans, a twelve-foot pug mill, a Freese auger machine of 50,000 brick capacity, a ten-track tunnel drier, and eight down-draft circular kilns, 28 feet in diameter. The upper part of plate XVII. shows the two clays and hoisting building at this plant.

Crescent Brick Plant of Mack Company.—The Crescent plant is nearly three-quarters of a mile below the Aetna and was started in 1856 by Atkinson & Garlick. It has 50,000 brick capacity with similar equipment to the Aetna and has eleven kilns, illustrated in upper part of plate XIII.

Clifton Sewer Pipe Plant of Mack Company.—The Clifton plant is at the side of the Crescent and is another early yard, started in 1844 by McCoy & Shawl. The equipment consists of a wet pan, three dry floors, a Means press with 40-inch steam cylinder and 18-inch clay cylinder. The sewer pipe were burned in twelve kilns, 28 and 30 feet in diameter. The plant has been idle since 1902. A photograph of this plant is given in lower part of plate XIII.

Sligo Sewer Pipe Plant of Mack Company.—The Sligo works are two miles below town, also started as a brick plant in 1844 by James Porter. It is equipped similar to the Clifton plant with eleven down-draft kilns, and also contains an equipment of brick machinery, but it has not been operated since 1902.

The early brick industry of West Virginia started in this section below New Cumberland near Kings creek and Holbert run. Remnants of the old kilns of the Kerr & Mahan yard are visible near Holbert's run. This plant, built in 1845, and the Freeman plant, built in 1858, at the mouth of the run, still show a few broken kilns. In 1837 Porter & Beall built a plant below New Cumberland and shipped brick by water to Wheeling and other points on the Ohio. This plant is now the property of the *Standish Brick Company*, consisting of a large four-story building equipped with brick machinery and eight round down-draft kilns, but the plant has not been operated for some years.

Near this last plant is the abandoned plant of the *Lone Star Brick Works* with a small auger machine, a nine-foot dry pan, and 12-arch brick drying floor, and five down-draft kilns. In 1846 two plants were started back of New Cumberland, up Hardin run, but they were soon abandoned. In the same year a plant was started at the north edge of New Cumberland and worked until the early '70's, the old stack being still there.

Porter Brick Company.—The Claymont plant of the Porter Company, started by Thomas Freeman in 1834, is located about one mile and a half below New Cumberland. It is built in two

sections, the lower one being equipped with a nine-foot dry pan, pug mill, Bucyrus auger machine of 30,000 capacity. The brick are burned in eleven round, down-draft kilns, 26 and 28 feet in diameter, holding 50,000 to 60,000 brick each.

The upper building, which is the original Freeman plant, is used for crushing the clay in a Blake crusher, with a capacity of 100 tons a day, and for hand molded fire brick made in various sizes and shapes. One man makes in a day 4,000 standard size brick, and 75 to 100 boiler slabs used for covering steam boilers. This section is also equipped with a small Raymond auger machine of 25,000 capacity used with several dies for brick and tile of various special designs. The brick molded by hand or on the special auger machine are dried on the large floor of the building by steam.

West Virginia Fire Clay Manufacturing Company.—This plant is located a mile below New Cumberland and was built in 1896. It is used entirely for crushing clay which is shipped to Pittsburg and Wheeling. The equipment consists of a Blake crusher and two nine-foot dry pans, giving a capacity of 200 tons of crushed clay a day, though in one special run 293 tons were crushed. The clay is obtained from mines just above the plant where the flint clay is six and one-half feet thick, covered with three feet of coal. The entry runs south of east for 800 feet in the old mine, but at that point the sandstone roof dipped down and cut out clay and coal, so a new entry was started below.

American Sewer Pipe Company.—The plant of this company is located a half mile below New Cumberland near the site of the old Black Horse tavern and was known as the Black Horse works, started in 1844 by James and William Porter. It was purchased by the present company in 1889. Sewer pipe was made here until 1896, when it was again converted into a brick plant and no pipe has been made since that year.

The brick are molded in a Freese auger machine which has a daily capacity of 60,000 building brick, or 40,000 paving blocks. The blocks are repressed on two double mold Raymond and two double mold Richardson machines. There are two drying tunnels, with nine tracks each. The clay is mined through an entry 2,300 feet long.

Acme Clay Works.—The Acme or Chapman plant is located at the upper end of the town of New Cumberland and used for

grinding flint clay for shipment. It was started in 1901 and is equipped with two dry pans having a daily capacity of 100 tons.

Clay Mines.—The railroad track at the Globe plant is about 35 feet above the level of water in the Ohio, and at this level or a few feet above is the Lower Kittanning clay which is not worked and the bank has caved over it so that its exact level cannot be determined. The upper clay (Middle Kittanning) is 50 to 80 feet higher and is opened by an entry driven east into the hill which has been worked a distance of 2,000 feet. (Plate XVII shows the position of the two clays at the Etna plant.) The clay has an average thickness of eight feet, though in a few places it reaches 15 feet and has 30 inches of coal over it with a cover of 30 to 40 feet of sandstone which pitches down in the New Cumberland area forming a roll cutting out the clay here and there.

The clay is hard, breaking with irregular fracture, and bluish-gray in color. It is hauled in mine cars to the tippie and dumped near the plant where it is left to weather for a time. The weathering action often being hastened by throwing steam and hot water over the piles of clay. The structure of the clay is similar in all the mines of this area and is shown in the following section at the Rocky Side mine:

	Feet.	Inches.
Sandstone	40	..
Coal	2½	..
Flint clay	6	..
Gray shale clay	4	..
Blue shale clay	12	..
Sandstone floor	4	..
Fine laminated shales	40	..
Coal (Lower Kittanning)	..	3
Clay	..	10

The bottom clay in this section is the Lower Kittanning, as also the coal above it. In working this clay there is considerable trouble with water, and the material has to be elevated to the plant. It is at the present time only used at the Etna works, but it is claimed to be especially adapted to sewer pipe manufacture, and when the sewer pipe plants were in operation here they used this clay in preference to the upper one, but for the past few years no pipe has been made as the plants are combined with others in different sections of the country into a large company whose present policy is to keep the West Virginia plants closed.

In the manufacture of brick and paving blocks, the flint clay, gray and blue shales are mixed together. These shales are more or less laminated clays of plastic variety and the color distinction is very slight. The coal and clays belong to the Middle Kittanning series with the Lower Freeport sandstone roof. The section of the hill above the Rocky Side mine shows the following formations above the mine:

	Feet.
Top of hill with sandstone boulders.	
Sandy shales and thin sandstones.....	90
Coal (formerly worked) Ohio No. 7.....	2
Shales	18
Finely weathered shale bed (opened for Bolivar clay but not found)	20
Shales and thin sandstone.....	110
Coal (formerly worked) Lower Freeport.....	2½
Shaly sandstone	90
Sandstone	40
Level coal and clay mine.	

The Upper Freeport coal appears to be absent in this section. Nearer the town of New Cumberland Dr. I. C. White measured the following section:¹

	Feet.	Inches.
Upper Freeport Coal, not present.		
Fire clay and limestone, Upper Freeport.....	5	0
Concealed and sandstone, massive.....	40	..
Flaggy sandstone and sandy shales.....	20	..
Coal "Roger" vein, Lower Freeport.....	3	4
Shales and concealed.....	30	..
Sandstone massive, Lower Freeport.....	70	..
Middle Kittanning coal.....	2	11
Fire clay and sandy shales.....	30	..
Lower Kittanning coal.....	3	..
Fire clay, Lower Kittanning.....	8	..
Sandy shales and concealed to low water in Ohio river...	50	..
Interval, estimated, to top of Pottsville.....	25	..
	287	3

At Kings creek, four miles south of New Cumberland, at the Casparis stone quarry, the order of the formation is shown as follows:

	Feet.	Inches.
Shale cover	20	..
Coal (Lower Freeport)	..	22
Clay and shale	4	..
Sandstone (Lower Freeport)	80	..
Coal (Middle Kittanning)	2	10
Fire clay	10+	..

1. W. Va. Geol Survey, Vol. II., p. 381.

The Middle Kittanning clay north of New Cumberland in its outcrop along the hill is very nearly level, with its floor 750 feet (determined by transit level) above sea, dipping at the north from the Union mine (750 feet) to the Rocky Side (732) and rising slightly at the Globe (737) in a distance of about three-fourths mile. For a mile from Clifton to the Union mine including the two Crescents, Aetna and Eagle mines, the floor of the clay is at the same level, 750 feet.

Traced to the east of Aetna mine the clay rises 24 feet in 1,200 feet across the sandstone roll, and the bottom of the sandstone roof rises 34 feet. The same clay at the mouth of Kings creek is 680 feet above sea, or a dip to the east of south of 70 feet in four miles, nearly 18 feet to the mile, and it passes under the Ohio river three-fourths of a mile below this place.

Sandstone Roll.—The sandstone roof of the coal and clay runs quite uneven, bending down and cutting out part of the lower layers. There appears to be one well defined roll of sandstone which completely cuts out the clay and coal under it.

This roll was found in the old mine at Rocky Side at 1,200 feet from the mouth of the entry and work was abandoned after penetrating it 600 feet. The shale remained below the sandstone, but the coal and flint clay were gone. A second entry was made to the north about 1,400 feet, and the roll was found at 100 feet, and a little further south the sandstone roll comes to the edge of the hill, showing some clay below it and bands of coal caught in the layers of sandstone. The new entry of Rocky Side, north of the other entries, runs north of east for 300 feet and the roll has not yet been encountered, but it is found in the Globe mine a short distance north. In the middle Rocky Side mine, south of the entries described above, the roll was struck 730 feet in the entry, further south in Union mine, it was found at 1,250 feet, and at the lower Union entry, at 1,200 feet.

Deep Gut run bends around back of these mines in a deep ravine and cuts across the sandstone roll which is there 1,200 wide. Approaching the roll from the west, the coal disappears and the clay changes to a sandy shale which soon pinches out, a sandstone layer below and one above the clay coming together. Nodular and lenticular masses of coal are caught in the sandstone, in a number of places in long narrow stringers one and one-half to three inches thick. In one place a mass of coal forms a small

core in a large block of sandstone. The lower sandstone bed is broken and wavy in its bedding forming miniature folds. Some of the sandstone courses are plainly cross bedded.

In one place, a foot of sandstone is cross bedded and over it is a few inches of sandstone with numerous small iron concretions and lenses of coal included. Over one of the abandoned entries on this side of the roll there are two feet of black shale, then thirty inches of coal with vertical fracture planes, and much broken, a branch of the coal bending with curved planes down into the black shale, the coal is covered by two feet of sandstone, then thirty inches of shale with the solid sandstone above. At this place the roof dips rapidly to the northwest and 100 feet in the hill cuts out the coal and clay. Both to the east and west of this entry the coal soon disappears. A small block only has been caught in the roll at this point. Farther to the east beyond the roll an entry has been driven into the hill and is following along the east side of the roll where the coal and clay are present in normal thickness. A new entry across the ravine is also clear of the roll.

South of town near Black Horse works, in the entry of the West Virginia Fire Clay Company, the roll was struck at 800 feet and was penetrated 200 feet below and abandoned. The coal and clay were absent below the roll and the shale was very hard. The new entry, about 600 feet east, shows the coal eight or ten feet lower than in the old entry and has not yet encountered the roll.

These measurements would give the general course of the sandstone roll as S. 30 E., but its course is more or less irregular. The presence this roll might possibly be explained by the assumption that the coal swamp on the border of the former sea was submerged, and as the Freeport sands were deposited over it, a strong current had its course across this particular area, cutting out the coal and clay, removing it in large part; later the channel was filled with sand, in part mixed with fragments of the coal, and raised into land leaving the record of the old current in this sandstone roll.

Chemical Analyses.—The clays selected for analysis were taken from the Clifton and Aetna mines, above New Cumberland. In the Clifton mine, the Middle Kittanning coal rests on six feet of bluish-gray flint fire clay, and below this are four feet of the

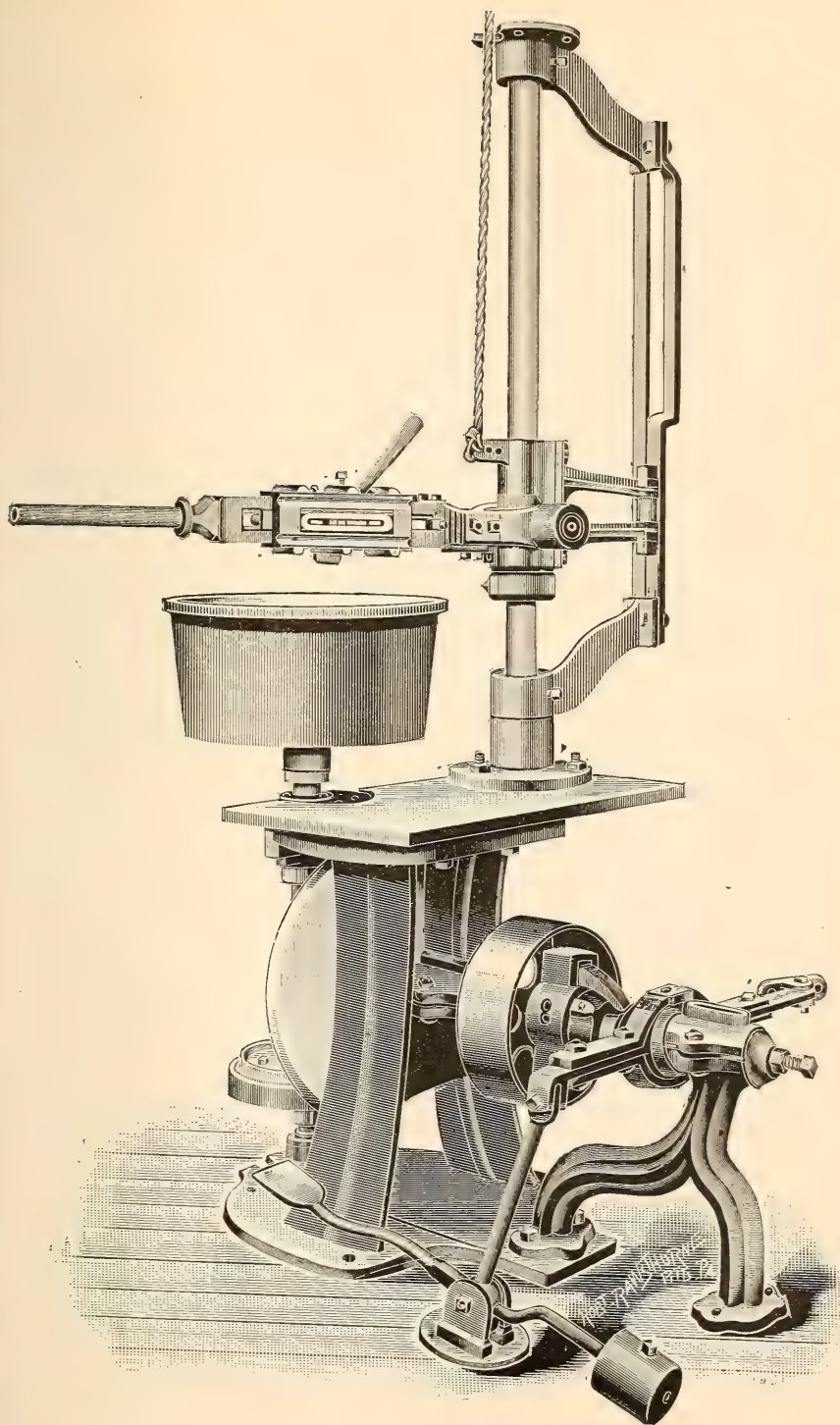


Plate XIV.—Patterson Jolly Wheel for Pottery Manufacture.

gray shale clay with ten to twelve feet of blue shale clay under the gray. In the manufacture of the brick the three varieties are mixed. Their composition is shown by the following analyses:

Clifton Mine, Middle Kittanning Clay and Shales.

	Flint clay.	Gray shale.	Blue shale.
Silica	52.24	57.58	59.76
Alumina	29.28	21.41	22.79
Ferric iron	2.73	3.75	0.60
Ferrous iron	0.51	3.45	3.53
Magnesia	0.20	1.44	1.23
Lime	0.68	0.46	0.59
Sodium	0.37	0.10	0.42
Potassium	2.11	3.14	3.79
Water	1.28	0.38	0.54
Titanium	1.20	0.84	0.82
Phosphorus	0.07	0.11	0.46
Loss on ignition	10.12	7.25	5.26
	100.79	99.91	99.79

The following analyses of the Mack Company clays were made by H. A. Wheeler of St. Louis, and kindly furnished the Survey by the officers of the Mack Company:

	UNION.			CRESCENT.	
	Rock.	Clay.	Shale.	Rock.	Clay.
Ignition Loss.....	8.76	8.93	7.66	8.36	10.87
Silica	55.99	62.92	60.88	55.12	56.84
Alumina	19.03	24.07	19.74	20.67	28.81
Oxide of iron.....	10.04	1.39	7.85	9.83	1.76
Lime	0.81	0.48	0.63	0.74	0.28
Magnesia	1.70	0.55	1.48	1.95	0.41
Alkalies	3.42	1.89	2.01	3.46	1.02
Totals.....	99.75	100.23	100.25	100.13	99.99

	ROCKYSIDE.			ETNA.		
	Rock.	Clay.	Shale.	Rock.	Clay.	Loam.
Ignition Loss.	6.17	9.58	6.72	9.84	9.84	6.16
Silica	62.29	60.32	60.28	58.83	59.16	69.86
Alumina	19.32	25.94	20.13	20.27	25.09	15.25
Oxide of iron.	6.80	1.24	7.11	7.99	2.93	5.79
Lime	0.42	0.56	0.83	0.56	0.60	0.26
Magnesia ...	1.84	0.44	1.96	0.69	0.50	0.69
Alkalies	3.30	2.04	2.86	2.10	1.92	1.86
Totals...	100.14	100.12	99.89	100.28	100.04	99.87

The term rock in these analyses refers to the shale below the fire clay.

The fusible components reach 12.34 per cent. in the gray rock, 10.14 per cent. in the blue rock, and 6.59 per cent. in the flint clay. The percentages of silica and alumina agree fairly close, in the flint clay 81.52 per cent., in the gray rock 78.99 per cent., in the blue rock 82.55 per cent. The gray rock is high in iron, 7.20 per cent, but the mixture of clays burns buff in color.

A rational analysis of the flint clay would give:

Free silica	26.41	per cent.
Clay substance	67.66	" "
Feldspar	5.90	" "

The mechanical analysis of the same clay gives:

	Range of particles in millimeters.	Per cent.
Fine clay	0.0 to .001	5.00
Coarse clay	.001 to .005	4.6
Silt	.005 to .02	10.6
Fine sand	.02 to .15	9.7
Medium sand	.15 to 1.0	25.9
Coarse sand	1.0 to 4.0	42.9
Water		1.3
		100.0

Physical Properties.—The flint clay and gray rock slake to fine scales, while the blue rock does not slake for weeks in water. The flint clay requires 28 per cent. of water to develop a normal molding consistency, its maximum plasticity is 15, air shrinkage 4 per cent, tensile strength 58 pounds, or when weathered 96 pounds to the square inch. It vitrifies at cone 26 (3002° F.) with 2 per cent. fire shrinkage, and becomes viscous near cone 28 (3074° F.).

The gray rock requires 24 per cent for normal molding consistency, has maximum plasticity of 17, air shrinkage of 4 per cent., and tensile strength of 40 pounds, or if weathered reaches 85 pounds. Incipient fusion begins at cone 1 (2102° F.), with fire shrinkage of 5 per cent., it is vitrified at cone 5 (2246° F.) with shrinkage of 6 per cent., and burns brown.

The blue rock requires 26 per cent. water for normal molding consistency, its maximum plasticity is 15, air shrinkage 4 per cent., tensile strength 46 pounds, or if weathered 110 pounds. It begins to vitrify at cone 1 (2102° F.) with 3 per cent. shrinkage, and is complete at cone 5 (2246° F.), with shrinkage of 6 per cent. and burns to a light brown color.

The Lower Kittanning clay has been considered in this section of the State as especially adapted to the manufacture of sewer

pipe. The clay was sampled in an old entry at the Aetna plant. The analysis of this clay and of the overlying 40 feet of buff shales formerly used for common building brick are shown in the following table:

Aetna Mine, Lower Kittanning Clay and Shales.

	Clay.	Shales.
Silica	57.52	57.89
Alumina	21.76	21.59
Ferric iron	3.41	5.62
Ferrous iron	3.70	1.26
Magnesia	0.88	1.55
Lime	0.60	0.61
Sodium	0.03	0.29
Potassium	3.57	3.28
Water	0.86	1.27
Titanium	0.33	0.72
Phosphorus	0.14	0.21
Loss on ignition	7.27	6.18
	100.57	100.47

The percentage of fusible elements in the Lower Kittanning clay is 11.59, very much higher than in the Middle Kittanning flint clay, and its percentage of silica is higher, which is desirable in sewer pipe clays in order that the salt uniting with the silica may form a good glaze. Its composition agrees very closely with that of the Middle Kittanning gray shale clay. The composition is not very different from that of the overlying shales, though the physical appearance is in marked contrast. While the lower clay has the high percentage of iron, it burns to a light brown color.

Physical Properties.—The clay requires 26 per cent of water for normal molding consistency, its maximum plasticity is 17, air shrinkage $3\frac{1}{2}$ per cent., its tensile strength 40, or if weathered 68 pounds. Incipient fusion is reached at cone 1 (2102° F.), with shrinkage of 2 per cent, and complete vitrification at cone 5 (2246° F.), with 10 per cent. fire shrinkage.

The shale requires 27 per cent of water for normal molding consistency, its maximum plasticity is 15, air shrinkage 4 per cent, tensile strength 36 pounds, or if weathered 70 pounds. Incipient fusion occurs at cone 1 (2102° F.), and vitrification at cone 5 (2246° F.), with 8 per cent fire shrinkage, and the shale gives a red product.

Hammond, Taylor County.

The only other place in the State where the Kittanning clays are worked is at Hammond in Marion county, six miles south-east of Fairmont.

Hammond Fire Brick Company.—The Hammond brick plant has been in operation twenty to thirty years, and has been under the present ownership since 1899. It manufactures paving brick and four grades of fire brick: The "Glade," which is a silica or sand brick, the particles held together by a small amount of plastic fire clay; the "Hammond," made from the No. 1 fire clay; the "Deer Park," made from No. 2 fire clay; the "Bessemer," made from an impure fire clay and which represents their lowest grade of fire brick.

The clay is crushed in two dry pans and one wet pan, tempered in a pug mill and molded in a Raymond auger (No. 777) of 50,000 capacity, and repressed on two Victor machines. The brick are dried in a Standard steam tunnel drier with twelve tracks and capacity of 72,000 and burned in eight down-draft circular kilns 28 and 30 feet in diameter holding 50,000 and 65,000 brick each. The fire brick are molded by hand, dried on a heated floor, and burned in three up-draft kilns holding 40,000 each. Natural gas fuel is used for burning all the kilns.

Clay Mines.—The clay is mined under the hill through long entries 70 feet above the yard, and is carried in cars on an elevated track across to the plant and dumped. The bank shows three feet of flint clay, underlaid by six to eight feet of plastic fire clay.

The clay and its overlying coal belong to the Lower Kittanning, as shown by the following sections of the hill at the mines:

	Feet.	Inches.
Sandstone, massive, Lower Mahoning.....	60	• ..
Shales and concealed with thin coal bed.....	80	..
Coal, Lower Freeport.....	6	..
Concealed	25	..
Coal, Middle Kittanning.....	3	6
Fire clay, plastic	8	..
Sandstone, massive and concealed.....	100	..
Coal, Lower Kittanning.....	3	..
Fire clay (worked)	5 to 10	..
Concealed to level B. & O. R. R.....	70	..

Chemical Analyses.—Analyses were made of the flint clay and the plastic clay, which gave the following percentages:

	Flint clay.	Plastic clay
Silica	43.40	64.18
Alumina	39.55	22.16
Ferric iron	0.38	0.83
Ferrous iron	0.57	1.16
Magnesia	0.13	0.49
Lime	0.32	0.42
Sodium	Trace.	0.41
Potassium	0.20	2.52
Water	1.03	0.53
Titanium	1.84	0.62
Phosphorus	0.34	0.20
Loss on ignition	13.12	6.15
	100.88	99.67

These two clays show a much greater contrast in composition than those at New Cumberland. The Hammond clay is much lower in silica and higher in alumina than the Lower Kittanning clay at New Cumberland. Its proportion of fluxes is 1.6 per cent., as compared with 11.59 per cent. in the same clay at New Cumberland, or 6.59 per cent. in the upper clay at the same locality. Both of these Hammond clays are excellent fire clays.

The rational analyses of the fire clays of New Cumberland and Hammond show the qualities of these two good clays, remembering the feldspar is a fusible component:

	Hammond.	New Cumberland.
Free silica	28.72	26.44
Feldspar	2.00	5.90
Clay substance	69.28	67.66

Physical Properties.—The flint and plastic clays at Hammond slake very slowly. The flint clay requires 20 per cent. of water to develop its normal molding consistency; the maximum plasticity is 8, or in well weathered clay is 21, showing a remarkable increase in plasticity on weathering. The plasticity of the so-called plastic clay is less in its unweathered state than the flint, reaching $4\frac{1}{2}$. The air shrinkage of both clays is about the same, 3.5 per cent. The tensile strength of unweathered flint clay is 60 to 73 pounds, and in weathered clay reaches 100 pounds. The plastic clay has a tensile strength of 35 to 40 pounds.

The flint clay reaches vitrification at cone 30 (3146° F.) with very little shrinkage, and has a gray color. The plastic clay

is vitrified at cone 14 (2570° F.) with 10 per cent. fire shrinkage, and is viscous at cone 20 (2786°), burning to a buff color.

These clays, especially the flint clay, show on weathering a marked improvement in plasticity and tensile strength. It would make a great improvement in the working qualities of the clays if they could be mined and left exposed to the action of the elements. The weathered flint clay would require very little plastic clay admixture.

Piedmont.—Under the coal (Lower Kittanning) mined in the hills at Piedmont, there is a good deposit of plastic fire clay, three feet thick, and over the coal five feet of good plastic clay. These clays have never been used at this place, but would in all probability be desirable clays.

Kanawha Valley.—The coal in the Kanawha series which may be correlated with the Lower Kittanning is not yet certainly established. Several good deposits of fire clay occur in the Kanawha coal series, but the clays near these coals have not been used, nor carefully examined and tested.

Cascade, Preston County.—At Cascade, on Decker's creek, is a clay with the following composition:

Silica	46.74
Alumina	34.05
Ferric iron	0.90
Ferrous iron	0.18
Magnesia	0.37
Lime	0.21
Soda	0.07
Potash	0.17
Water	3.50
Titanium	2.28
Loss on ignition.....	12.00
	100.47

This is a flint clay, 12 feet thick in outcrop, with 4 or 5 feet of plastic clay below, and with only 1.9 per cent. of fluxes. It is located 12 miles from Morgantown, near the Morgantown & Kingwood railroad. Its position has not been accurately determined, but it appears to be near the Kittanning horizon. The analysis shows it to be a very valuable clay, as yet undeveloped.

UPPER FREEPORT CLAY.

The clay under the Upper Freeport coal has been named the Bolivar fire clay in Pennsylvania, and is an important fire clay

horizon. In West Virginia there are some good outcrops of this clay on Decker's creek, above Morgantown, near Dellslow, with railroad connection, and could be easily developed.

CONEMAUGH SERIES.

At the base of the Conemaugh series are two massive sandstones, Upper and Lower Mahoning, which in some parts of the State often come together, forming one massive stratum. In other sections the two are separated by shales, in which a coal seam is sometimes found, which is mined near New Cumberland, with a fire clay floor. In Wayne county, near Ceredo, the clay is present, but no coal. The clay is worked at but one place in the State.

Thornton, Taylor County.

Thornton Fire Brick Company.—The Thornton plant is located five miles east of Grafton, on the Baltimore & Ohio railroad, and was started in 1904. The equipment consists of a nine-foot dry pan, ten-foot pug mill, Bucyrus auger (No. 670) of 40,000 brick or 14,000 paving block capacity in ten hours, and Eagle repress. The brick are dried in hot air tunnel drier of 30,000 capacity. The heat for the drier is drawn from the cooling kilns. The brick are burned in six round down-draft kilns, 30 feet in diameter, holding 80,000 brick each, which are burned with gas in about ten days.

A new wing of the plant has been erected for manufacture of fire brick molded by hand. The floor is paved with Berea flag stone, heated by steam, and arranged in twenty-four sections. The room is 75 by 150 feet, and will hold 25,000 brick, while the daily capacity will be 15,000. The shed is of substantial construction, and the clay is ground in a seven and one-half foot wet pan, placed above the floor level.

Clay Mine.—The clay is obtained by drifting into the hill at a level about 60 feet above the brick yard. The mine shows 18 feet of flint and soft clay, and in one place reaches 22 feet. The distribution of the flint and soft plastic clay is irregular. In some parts of the mine the soft plastic clay cuts out the flint clay entirely. The soft clay is sometimes above and sometimes below the flint. The roof and floor of the mine are sandstone, and the mine is dry. The weekly output is about 400 tons of clay. The

clay burns buff, while the shales below, at level of the plant are 22 feet thick, and burn red.

It is difficult to secure good sections of the hill, on account of the vegetation and talus, but a comparison with the Newburg section and at Grafton with barometer levels seems to show that this clay is at the horizon of the Mahoning coal. The same clay was formerly worked for a short time one mile south of Thornton by the West Virginia Fire Clay Company, which burned two up-draft temporary kilns of brick, and then the plant was abandoned.

Chemical Analyses.—The chemical composition of the flint and plastic clays from the Thornton mine are shown in the following analyses:

Thornton Mine Clays.

	Flint clay.	Plastic clay.
Silica	66.69	56.19
Alumina	21.83	26.31
Ferric iron	0.37	2.82
Ferrous iron	1.00	0.96
Magnesia	0.10	1.44
Lime	0.33	0.39
Sodium	0.08	0.50
Potassium	0.48	3.90
Water	0.99	1.39
Titanium	1.11	0.63
Phosphorus	Trace.	Trace.
Loss on ignition	7.13	5.48
	100.11	100.01

The plastic clay contains 82.5 per cent. of silica and alumina, and the flint clay has 88.52 per cent, which is higher than any of the flint clays so far discussed. The proportion of fluxes in the flint clay is 2.36 lower than any of the flint clays described, except the Hammond and Piedmont. The percentage of fluxing elements in the plastic clay is much higher, 10.01 per cent. The iron percentage is low, especially in the flint clay.

The rational analysis of the Thornton flint clay gives:

Feldspar	32.43
Free silica	18.95
Clay substance	48.62

Physical Properties.—The plastic soft clay slakes to fine scales, but the flint clay does not slake in a few week's time. The water required to produce a normal molding consistency in the soft clay is 24 per cent., and 20 per cent. for the flint clay. The plasticity of the soft clay reaches 17 and for the flint 3, but in the

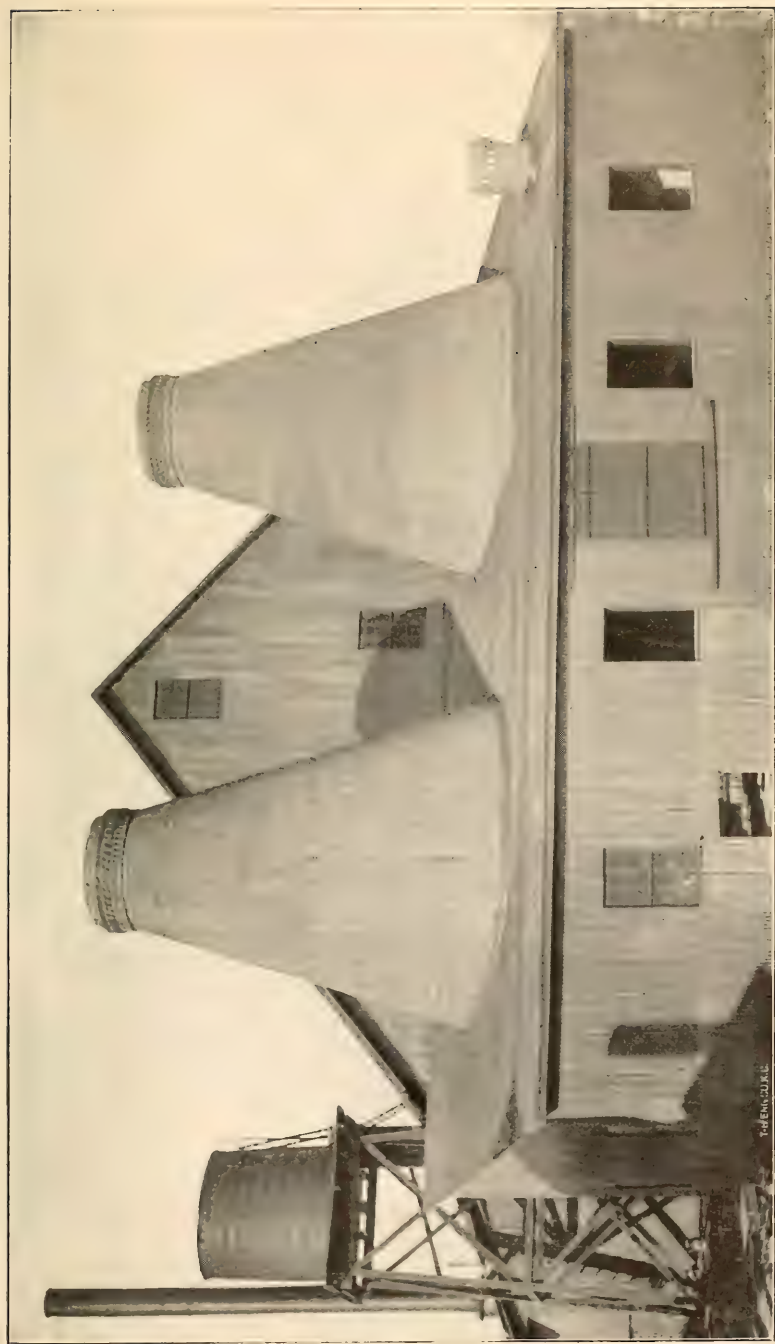


Plate XV.—Parkersburg Semi-Vitreous Porcelain Pottery.

weathered plastic clay it reaches 24, and in weathered flint clays 13. The tensile strength of the plastic clay is 89 to 100 pounds, which in weathered clay reaches 151 pounds. The tensile strength of the flint clay is 75 to 90 pounds, and in weathered clay, 114 pounds. These tests show the great advantage of weathering the clays before use. The air shrinkage in both clays is about 4 per cent.

The flint clay reaches vitrification at cone 30 (3146° F.), with no shrinkage, and the plastic clay at cone 1 (2102° F.), with complete vitrification at 5 (2246° F.), with 6 per cent. fire shrinkage.

Junior, Barbour County.

One mile east of Junior, on the Hilyard farm, is a stratum of flint fire clay exposed in a ploughed field. The vein has not been opened, but it is six or eight feet in thickness, with no trace of coal near it. The level of this clay is about 160 feet above the coal mined near the town. The clay is hard, bluish gray to light brown in color, and breaks with smooth fracture. The horizon would be near that of the Thornton deposit.

Charleston, Kanawha County.

In the Charleston region there have been a number of brick plants in operation at various times, a number of which have been unsuccessful on account of poor business management rather than on account of the quality of the clays. The first brick paved street in the United States was laid in Charleston in 1872. One block of Summers street, nearest the Kanawha river, was paved with brick set on sand, with a sub-structure of planks dipped in tar and also resting on sand. This block is still in use, and the street at this day is in very fair condition. For a number of years after that date, the Charleston brick were shipped into Ohio, and the first brick paved streets in Columbus in the early 80's were laid with the Charleston brick, set on tarred planks.

With the opening of the paving industry in Ohio, the sale of Charleston brick was confined to the State, and in later years they were used mainly for local trade, very few paving brick being shipped away. At the present time no paving brick are made at Charleston.

Some of the best fire brick in the State were made for a number of years on Elk river, just above Charleston, but at the

present time no fire brick are made in this vicinity. Near Charleston are located some deposits of fire clay equal to the best in the State, and to be favorably compared with standard fire clays of the Eastern States. These clays and shales make paving brick of the highest quality, and the deposits are almost unlimited. They burn both buff and red, making fine grades of pressed and ornamental building brick. Here also occur fine grained clays adapted to manufacture of pressed brick and tile, also good stone-ware clays.

The area of these clays is large, and their location is close to the Great Kanawha Valley coal fields, and gas fuel is also available. Three lines of railroads reach the field, and the Kanawha furnishes water transportation for fuel and for the finished product. With all these natural advantages, the Charleston region should be the greatest center of clay industries in the State, but at the present time there are only three small yards using the river clays and one yard using the clay mined in the hill.

It is difficult to explain the causes of the non-development of this field. There have been some discouraging failures in plants in this region, but in no case have they been due in any degree to the character of the clays. It is hoped that when the natural advantages of this region for clay working in its different lines are fully appreciated capital will come in to develop the field properly. Clay products should be shipped out of this territory to supply the trade not only of West Virginia, but of the cities east, south, and even west. A careful examination of the results of the investigation of these clays now to be given, will show their high character, and their location, in part. It must be remembered that the report of these Charleston clays is not complete, and there probably exist other important deposits that were not visited in the course of this investigation. The clays which have been developed near Charleston belong to the *Conemaugh Series* and the uppermost *Kanawha Series*.

Kanawha Brick Company.—This plant, located about one mile east of the Chesapeake & Ohio railroad station, was built by W. O. Isaacs, in 1897. For common red building brick, the river sandy clay is used from a large pit worked below the level of the plant. The company now makes a specialty of buff building brick, made from a clay hauled one mile from the mines up Lick

Branch run. It also manufactures a dark trimming brick by adding manganese to the buff burning clay.

The equipment consists of a seven-foot dry pan, twelve-foot pug mill, Bucyrus auger machine, run at 25,000 brick capacity in ten hours, two Eagle represses, a Boyd dry press being used at the present time for the buff front brick. Natural gas fuel is used and the brick are dried in a nine tunnel drier of 50,000 capacity and burned in three circular down-draft kilns, 30 feet in diameter, holding 45,000 brick each, and in three up-draft 21-arch permanent wall kilns of 390,000 brick capacity.

Clay Mines.—The clay mines are located about one mile from the plant, or three-quarters of a mile up Lick Branch, and the entry was driven into the hill about 200 feet. At the present time the clay is taken from a new mine, across the ravine from the old one, and at a little lower level. At the mouth of the entry the clay was six feet and ten inches thick, the upper two feet and ten inches burned buff, while the lower four feet burned red. Farther in the entry, practically all the clay burned buff, and the analyses of the upper part and the lower part of the seam showed but little difference in composition. Over the clay are ten inches of coal, and above this a massive sandstone, of which ten feet are exposed. Across the ravine the same order of strata may be observed with 30 inches of coal below the clay, then four to six feet of shales exposed, and farther down the hill comes another heavy sandstone.

The 30-inch vein of coal has been worked in a number of small banks in this run, and in the next run below, Porter's run. It has a tendency to split into two veins, separated in Lick run by the clay, and in the Porter's run section by sandstone. This coal is in all probability the North Coalburg bed of the Kanawha Series.

The section on Porter's run, as given by Dr. I. C. White, includes the following formations, with the former identification omitted:¹

1. W. Va. Geol. Survey, Vol. II., p. 303.

	Feet.	Inches.
Sandstone, massive	80	..
Coal	0	4
Fire clay, impure	4	..
Concealed	20	..
Iron ore, sandy	0	6
Blue shale	3	..
North Coalburg. {	Coal	2 2
	Black slate.....	1 6
	Sandstone, massive.....	15 ..
	Coal, good.....	1 6
Sandstone, massive	60	..
Coal, slaty (No. 5 Block)	1	..
Sandstone	50	..
Shales and concealed	30	..
Kanawha black flint	5	..

Chemical Analyses.—The upper and lower parts of the clay seam in the Lick Branch run were examined, but the analyses fail to show much difference, and both should burn buff. Near the outcrop the lower half of the seam was said to burn red. If this was true of the outcrop that character has disappeared as the clay was followed into the hill:

	Upper part.	Lower part.
Silica	61.92	60.29
Alumina	23.32	23.77
Ferric iron	0.52	0.27
Ferrous iron	2.86	2.95
Magnesium	0.78	1.59
Lime	0.42	0.54
Sodium	0.27	0.20
Potassium	2.91	3.49
Water	1.01	0.56
Titanium	0.40	0.83
Phosphorus	Trace.	Trace.
Loss on ignition	6.04	5.27
	100.45	99.76

The percentage of titanium in the upper part of the stratum was the lowest found in any clay examined. The percentage of fluxes in the upper part is 7.76 and in the lower part 9.04.

Physical Properties.—This clay slakes readily to scales. It requires 29 per cent. of water to develop its normal molding consistency; the maximum plasticity is 9. The air shrinkage is about 4 per cent. and the tensile strength of the unweathered clay is 79 to 88 pounds and in weathered clay 105 pounds to the square inch.

Incipient vitrification occurs at cone 1 (2102° F.), vitrification at cone 5 (2246° F.), viscous above cone 14 (2570° F.), with fire shrinkage of 4 per cent.

This buff burning clay is also found in the other creek valleys near Charleston. On Ferry branch, at the Dewey farm, the buff burning clay is 22 feet thick, with five to ten feet of cover over an area of 30 acres, with a two foot vein of coal under it.

Kanawha and New River Fire Brick Company.—The plant of this company was built near the close of the year 1902, two and one-half miles west of Charleston, on the Kanawha & Michigan railroad. The plant was a very substantial one, with a large equipment of machinery, housed in large and well constructed buildings. The cars were hauled from the mine by electric trolley and the buildings lighted by electricity. It was one of the most expensive plants in the State, but was destroyed by fire in the fall of 1904 and has not been rebuilt. It manufactured fire brick, building brick, and a very high quality of paving block. The destruction of the plant was a great loss to the brick industry of the State.

The equipment consisted of two nine-foot Stevenson dry pans, one Martin wet pan, twelve-foot pug mill, Freese auger brick machine (Mammoth Junior) of 75,000 capacity, two Raymond represses. The brick were dried in a hot air tunnel drier of eight tunnels, with capacity of 75,000 brick. The fire brick molded by hand were dried on a floor above the drier tunnels. Hot air was forced into the drier by a large fan. The brick were burned in eight round down-draft kilns, 28 and 30 feet in diameter, holding 40,000 blocks, and in five square down-draft kilns, holding 70,000 paving blocks. These blocks were made $8\frac{1}{2} \times 2\frac{7}{8} \times 4$ inches in size.

Clay Mine.—The clay mine is located at the side of the county road, over one-half mile north of the plant, and is opened by three entries, one of which is illustrated in Plate XVIII., which also shows the sandstone above the clay and shale.

The bank at the mine shows the following strata:

	Feet.	Inches.
Shales, red and buff.....	30	..
Coal (Barton)	..	8
Sandstone, Buffalo	30	..
Blue shale	1	..
Clay red, blue and buff	12	..
Fire clay	5	..
Blue shale	8+	..

In the manufacture of fire brick, the fire clay was used with a little of the overlying clay added to it. In the manufacture of paving brick, the fire clay and red and blue clays were mixed with the top red and buff shales about half and half.

A short distance south of the mine, a blossom of coal shows at the bend of the road, with a sandstone ledge ten feet above it. The dip to the mine and beyond is very steep, carrying the section below the road in a few hundred yards. A study of this section compared with other sections in this area would indicate that the heavy sandstone above the fire clay and shales is the Buffalo, with the Bakerstown or Barton coal above, covered by the Pittsburgh red shales. The fire clay, blue and red clays would be of the same horizon as the Thornton clay worked near Grafton.

The fire clay and associated mottled clays are found one mile east, by the road side and up Woodward creek, and of apparently the same quality. Along this creek is a deposit of pottery clay which has not been developed. A pit dug in the fire clay horizon shows twelve feet of fire clay, red and blue clays. Over 100 feet of the upper shale is exposed on the hill to the west of this creek. Twenty feet of the top of this shale is buff in color, and weathers into fine flaky particles which burn to a good red brick, while the clays and shales at the Kanawha and New River Company's mine burn buff.

The upper red and buff shales above this mine are tilted in places and the bedding planes are irregular. About five feet from the bottom is a row of limestone nodules some three and four feet in diameter.

Chemical Analyses.

Kanawha and New River Brick Co. Mines.

	Flint clay. Shale.	
Silica	54.49	51.07
Alumina	29.94	25.78
Ferric iron.....	1.67	3.08
Ferrous iron	0.04	3.75
Magnesia	0.18	1.26
Lime	0.52	0.57
Sodium	0.21	0.17
Potassium	0.17	3.27
Water	1.53	1.41
Titanium	1.15	1.01
Phosphorus	0.26	0.14
Loss on ignition	10.65	8.70
	100.81	100.21

Physical Properties.—The flint clay requires 26 per cent. of water to develop a normal molding consistency with a maximum plasticity of 6. Its air shrinkage is $2\frac{1}{2}$ per cent., tensile strength 34 pounds. Its fire shrinkage is 4 per cent., burning nearly white with incipient fusion at cone 27 (3038° F.), and vitrifies at about cone 31 (3182° F.) The maximum plasticity of the shale below the flint clay is 19, air shrinkage $5\frac{1}{2}$ per cent., and tensile strength 57 pounds.

Charleston Fire Brick Company.—The plant of this company is located up Elk river two miles from Charleston at Two Mile creek station on the Coal & Coke railroad. It is one of the old brick yards of the Charleston region, and has been used from time to time for the manufacture of fire brick, but it has been idle since 1901. During that year 1,500,000 fire brick were made for the coke ovens of the Kay Coal Company.

The capacity of the plant is 25,000 brick a day. The plant is equipped for the manufacture of stiff-mud building brick, though none has been made for some years. The equipment consists of a nine-foot dry pan, six-foot wooden pug mill, Bucyrus auger of 30,000 capacity, Eagle repress. The building brick were dried in nine-track tunnel drier heated by fires below. The fire brick were dried on a heated floor large enough to hold 10,000 brick. The building brick were burned in one up-draft kiln, and the fire brick in two round down-draft kilns, 26 feet in diameter, drawing into one stack.

The river clay from a ten-foot pit near the mill was used for building brick. The fire brick were made from a mixture of one-third flint clay and about two-thirds plastic clay from the mine on the hill back of the plant.

Clay Mine.—The clay is worked in an open pit one mile and a half from the plant on Elk, and 180 feet above the level of the plant. This mine could be reached by wagon road and the clay was formerly hauled to the plant by this route. Later a track was built from the mine around the hill to an incline 140 feet above the yard and the cars were taken down the incline by cable and across the railroad on raised trestle to be dumped at the mill. This track is now in bad repair but could be renewed at no great cost.

The clay pit has caved along the banks and the talus covers the flint clay over much of its surface. A section of the pit shows the following layers:

	Feet.
Cover of soil and sandy shale.....	10 to 25
Sandy shales	4
Buff shale	1
Faint coal blossom	..
Blue shales and clay, plastic	10
Flint clay	4
Buff shales and clay, plastic	10

Below the pit in the ravine is a massive sandstone and the interval to the bed of the creek is 145 feet. The horizon is apparently lower than the Bakerstown or Barton coal, and may be designated as the Elk fire clay. It is probably the same as that on Two Mile.

A section near this point on Two Mile creek shows the following order of the rocks:¹

	Feet.
Flaggy sandstone	20
Coal, Bakerstown (Barton)	3
Sandstone, massive	15
Shales, with gray limestone	20
Sandstone, massive	25
Fire clay, Elk.....	8
Sandstone and concealed	85
Sandstone	75
Coal, Mason	2
Sandstone, Mahoning	120
Shales, sandy	10
Kanawha black flint	5

Chemical Analyses.—Analyses were made of the flint clay and the overlying blue plastic shales which weather to clay and appear to be very similar to the shales below the flint clay.

	Flint clay.	Plastic shaly clay.
Silica	53.41	50.57
Alumina	31.38	30.05
Ferric iron	1.44	3.43
Ferrous iron	0.25	0.21
Magnesium	0.06	0.45
Lime	0.22	0.68
Sodium	0.21	0.51
Potassium	1.03	2.02
Water	0.95	1.55
Titanium	1.10	0.81
Phosphorus	0.31	Trace.
Loss on ignition	9.74	9.68
	100.10	99.96

1. W. Va. Geol. Survey, Vol. II., p. 240.

The proportion of fluxes in this flint clay is 3.21, which compares favorably with other good fire clays. The proportion of fluxes in the plastic clay is 7.30. The iron is low in amount and the clays and shales burn buff.

Physical Properties.—Both of these clays slake readily and require about 25 per cent. of water to develop their normal molding consistency; the maximum plasticity in the flint clay is 14, or when weathered reaches 20, and in the so-called plastic clay is 10. The air shrinkage of the flint clay is 4 per cent., and 6 per cent. in the shale clay. The tensile strength of the flint clay is 63 to 67 pounds, or when weathered, 85 pounds; and in the shale clay the tensile strength is 112 to 115 pounds, or when weathered 157.

The flint clay does not show incipient fusion until above cone 30 (3146° F.). The plastic clay reaches incipient fusion at cone 20 and vitrifies completely at cone 27 with a total fire shrinkage of 3 per cent. Both clays burn to a gray color.

Mechanical Analysis.—The plastic shale clay shows the following proportions of grains of different sizes:

	Range in millimeters.	Per cent.
Fine clay	.00 to .001	10.0
Coarse clay	.001 to .005	12.5
Silt	.005 to .02	19.6
Fine sand	.02 to .15	13.6
Medium sand	.15 to 1.0	27.2
Coarse sand	1.0 to 3.0	15.6
Water		1.5

Barlow, Kanawha County.

On the McDonald farm at Barlow, in a railroad cut one-half mile above the station, a clay of apparently very good quality is seen. It is under the massive sandstone which is probably the Salzburg, bringing this clay at the horizon of the Bakerstown or Barton coal. The clay has been opened in a shallow pit, but has not yet been used. The small pit shows under the massive sandstone three feet of buff sandy shales then twelve feet of blue clay which in places is almost white.

An analysis of this clay which is found at various places in this neighborhood shows the following composition:

	Per cent.
Silica	49.81
Alumina	33.85
Ferric iron	0.68
Ferrous iron	0.26

Magnesium	0.43
Lime	0.36
Sodium	0.40
Potassium	1.36
Water	1.38
Titanium	1.59
Phosphorus	0.09
Loss on ignition	10.30
	100.51

With the small percentage of iron this clay should burn buff, its proportion of fusible elements is low, 3.49 per cent.

A rational analysis gives the following:

	Per cent.
Free silica	7.05
Feldspar	11.09
Clay substance	81.86

Physical Properties.—This clay slakes in a half minute and requires 18 per cent. of water to bring it to a normal molding consistency. Its maximum plasticity is 15, and air shrinkage 6 per cent. The tensile strength is 50 pounds to square inch, or when weathered reaches 104 pounds. Weathering of this clay doubles its strength.

The clay reaches incipient fusion at cone 14 (2570° F.), vitrification at cone 21 (2822° F.), completed at cone 27, with a total fire shrinkage of 7 per cent.

Morgantown, Monongalia County.

At Morgantown, there is exposed a very complete section of the *Conemaugh Series* from the Pittsburg coal at the top to the Mahoning sandstone at the bottom. A number of shales and clays are shown in the section which is given in this connection.¹

	Feet.	Inches.
Pittsburg coal	..	..
Fire clay	2	..
Sandy shales and sandstone	32	..
Coal, Little Pittsburg	1	6
Sandy shales	17	..
Limestone	1	..
Yellowish shales with iron ore	10	..
Sandy shales and concealed	17	..
Sandstone, rather massive	25	..
Sandy shales and concealed	15	..
Massive sandstone, Connellsville	20	..
Bluish green sandy beds	20	..
Black slate, fossiliferous	1	..
Limestone, Clarksburg	1	..

1. W. Va. Geol. Survey, Vol. II., p. 230.

Shales and sandy beds	45	..
Sandstone, Morgantown	20	..
Elk Lick coal	3	..
Shales and concealed	55	..
Limestone, Crinoidal, Ames	1	6
Variegated shales, Pittsburg red shales.....	85	6
Limestone, Upper Cambridge	1	..
Shales	14	..
Sandstone, Buffalo	3	6
Shales and shaly sandstone	30	....
Massive sandstone, Upper and Lower Mahoning.....	100	..
Shales	40	..
	561	0

The only plant in this county using any of these shales or clays for manufacture of brick is working on the Pittsburg red shale.

Morgantown Brick Works.—This plant is located at the northeastern edge of town below the station of Seneca at the side of the Baltimore & Ohio railroad.

The works were started in 1899 and the equipment consists of a Stevenson crusher, two nine-foot Stevenson dry pans, pug mill, a Raymond auger machine of 50,000 brick daily capacity, a Victor repress. The brick are dried in a Sharer five-track drier heated by fires below, and holding 35,000 to 40,000 brick. The brick are burned in eight round down-draft kilns, most of which hold 50,000 brick, and one up-draft kiln of 80,000 capacity. Both building brick and paving brick are made, which are burned with natural gas and have a red color. The shale pit shows fifteen feet of working face and is worked in an open cut. The quantity of shale at this locality is almost unlimited.

Chemical Analysis.—The shale used at the Morgantown Brick Works shows the following components on analysis:

	Per cent.
Silica	55.63
Alumina	20.76
Ferric iron	3.94
Ferrous iron	4.17
Magnesium	1.70
Lime	0.86
Sodium	0.34
Potassium	2.97
Water	1.03
Titanium	0.98
Phosphorus	0.23
Sulphur	Trace.
Loss on ignition	6.98
	99.59

The percentage of iron is 8.11, almost one-half being ferric iron, which determines the red color of the burned clay. The proportion of fluxes is high, 13.98 per cent.

Physical Properties.—The shale slakes in a short time leaving harder lumps in the slaked mass, which require a longer time to fall into pieces. It requires 22 per cent of water to develop its normal molding consistency. Its maximum plasticity is 18, its air shrinkage $4\frac{1}{2}$ per cent. The tensile strength averages 109 pounds and reaches 132 pounds, or when weathered averages 141 pounds.

The clay vitrifies at cone 1 (2102° F.), with a fire shrinkage of 2 per cent., and is viscous at cone 5 (2246° F.), with a slight increase in bulk.

Charleston, Kanawha County.

The shales found on Two Mile creek and used by the Kanawha and New River Brick Company were traced into the hills to the east near the Hanna farm, as described in an earlier section. Shales of the same horizon were found at Barlow a few miles up Elk river, on the McDonald farm about 80 feet above the blue clay described above, from the same farm. Fifteen feet of shales are exposed to the top of the hill, with heavy sandstone below. The horizon of these shales is that of the Pittsburg red shale, the same as at Morgantown.

Both of these shales near Charleston burn red, making a high grade building brick, and are accessible to the railroad. The McDonald shale is only a short distance from the Coal & Coke railroad, while that on the Hanna farm is about one-half mile from the Kanawha & Michigan road. Neither deposit has been developed, though both have been tested in a practical way in the local brick yards with marked success. The analyses of these shales show a close resemblance to the Morgantown shale, except they have a higher percentage of ferric iron.

	Hanna farm.	McDonald farm.
Silica	54.34	56.78
Alumina	22.01	22.53
Ferric iron	8.51	5.24
Ferrous iron	0.37	0.76
Magnesium	1.17	1.32
Lime	0.14	0.68
Sodium	0.27	0.28
Potassium	3.08	3.27

Water	2.54	2.27
Titanium	0.85	0.83
Phosphorus	0.22	Trace.
Loss on ignition	6.29	6.43
	100.09	100.39

These shales are five miles apart, and show a very close agreement in composition, and their physical appearance is similar and in all probability they belong in the Pittsburgh red shale horizon.

Physical Properties.—Both shales slake very slowly. The Hanna shale requires 30 per cent. of water, and the McDonald shale 25 per cent. of water to develop their normal molding consistency. The maximum plasticity of the former is 10, and of the latter 14. The air shrinkage of both shales is 6 per cent. The tensile strength of the Hanna shale is 100 pounds with a maximum of 111 pounds, and when weathered it reaches 133 pounds to the square inch. The tensile strength of the McDonald shale is 97 pounds with a maximum of 110 pounds, and in weathered shale increases to 140 pounds to the square inch.

The Hanna shale begins to vitrify at cone 1 (2102° F.), and is completely vitrified at cone 5 (2246° F.), with little shrinkage and burns to red color. The McDonald shale shows incipient fusion at cone 1 (2102° F.) with 11 per cent. fire shrinkage, and is vitrified at cone 5 (2246° F.), changing from red to black color.

Huntington, Cabell County.

In addition to the river clays in the Huntington region, there are excellent and large deposits of clays and shales in the hills which would be available for a variety of clay industries. So far only two plants are using these clays, one for the manufacture of brick and the other for roofing tile. As these two plants are using the shales from the same horizon, the shales will be discussed together after the description of the plants.

The Ohio Clay Shingle Company.—There are only two roofing tile plants in the State, one at Parkersburg using a shale in the Dunkard series, and the one at Huntington using shale from the Conemaugh. Both groups of shale are adapted to the manufacture of a roofing tile of good quality and color.

The Huntington plant was started in 1899 and is located one mile and a half southwest of Huntington on Sixteenth street. A brick plant was started on this location in 1891 under the name of the Huntington Paving & Pressed Brick Company, and used a

deposit of sandy river clay which made a low grade of brick.

The shales are ground in a nine-foot Bucyrus dry pan and tempered in a seven-foot pug mill, then further tempered in a short pug mill attached to the two small auger Murray tile machines made under patents controlled by the company.

The tile are dried in a six-track steam tunnel drier using exhaust steam by day and live steam at night. The drier holds 92 steel rack cars with 272 tile to the car: The tile are placed in square sagger boxes with movable sides, each compartment holding forty-eight tile. These saggars are built of fire clay slabs, 16x7x2 inches in size, placed in the kilns. There are two down-draft kilns with ten fire holes and twelve chimneys, also one double down-draft kiln with twenty fire holes, all made square, and each holding 110,000 shingle tile. The tile are dried 24 hours and in the kilns are water smoked three days with wood fuel, then burned with coal for seven to nine days and the kiln left eight to ten days to cool. In order to give greater drying capacity, there are two open sheds with canvas sides and permanent roof used for the storage of the tile from the drier before filling the kiln.

The tile are made in the form of flat shingles which measure before burning $14\frac{1}{2} \times 6\frac{1}{4} \times 6-16$ inches, and after burning measure $13\frac{3}{4} \times 6 \times 6-16$ inches. The tile are vitrified in part, are of a good deep red color and are very strong. They have given satisfaction in use and have been used on many private and public buildings in this State and have been shipped to Chicago and farther west. The shape of the tile is shown in figure 18.



Fig. 18.—Huntington Shingle Roofing Tile.

Tile roofing has the quality of permanence, being very durable and is adapted to the production of beautiful architectural effects. Formerly it was laid in cement and the resulting great weight required reinforced roofs and hindered its adoption in many cases. Tile roof is now nailed to the board substructure of the roof without using cement, so that it is becoming a rival to slate. Its cost was formerly greatly in excess of slate, but this difference has been much reduced. The flat shingle tile have grown in popularity and this company makes no other shapes up to the present time on account of the demand for a plain tile of good color.

West Virginia Paving and Pressed Brick Company.—The brick plant of this company is located about 300 yards nearer town than the last plant, and was started in 1903. The equipment consists of a nine-foot dry pan, Freese auger machine, combined with six-foot pug mill, giving a capacity of 50,000 brick a day, though the present output is about half this amount, also a Richardson two-mold repress.

The brick are dried in a five-track tunnel steam drier holding 72 cars, giving a drying capacity of 35,000. The brick are burned in three 16-arch permanent wall up-draft kilns holding 260,000 brick each, and one 14-arch up-draft kiln holding 200,000 brick. The shales used are at same horizon as the lower pit of the tile or shingle plant, and burn to a deep red color. Both of these plants are connected by switch with the Chesapeake & Ohio railroad.

Shale Pits.—In the shale pit back of the brick plant, the floor is a limestone, four feet thick, with blue shales below which are not used; and above the limestone are fourteen feet of bluish shales and clay which weather buff, then ten feet of soft buff clay and shale.

At the clay shingle plant the sandy river clays are found around the plant eight to twenty feet in depth and are no longer used. Across the road from the mill are the two pits of shale now used. The lower one shows 12 to 15 feet of red shale weathering brown or buff, especially in the upper portion, and covered by one and one-half feet of red clay and shale, sticky when wet, and not used. At the top is the cover of three feet of soil and clay.

In the brick plant pit this section rests on limestone and a short distance east a nodular limestone is seen at the level of the

bottom of this pit. Near the bottom of the red shale are found numerous fossils, and through the red shale are small, hard, red nodules of concretions.

The upper pit of the clay shingle plant is 15 feet higher than the top of the lower one, and has a sandstone floor. The section shows 15 to 20 feet of yellow or buff, sandy shales with five or six feet of soil and clay cover. A short distance east and 20 feet above the top of this pit is a 15-foot solid ledge of sandstone quarried for building stone.

In the manufacture of the roofing tile, the upper sandy shale is blasted out and spread over the ground to weather. When left for several weeks or months it crumbles into fine flakes and works much better in the mixtures. The red shale from the lower pit and the buff sandy shales from the upper pit are mixed about half and half. They are hauled to the plant in dump carts. The section of the hills near these plants shows the following order of strata :

	Feet.
Sandy shales to top of the hill.....	45
Coal blossom	..
Sandy shale and shaly sandstone	45
Shaly sandstone	4
Sandstone, solid ledge, Morgantown	15
Sandy shales, and concealed	20
Yellow or buff shales, used.....	20
Sandstone and shales.....	30
Red shales, used	16
Limestone, Ewing	4
Blue shales	..

The limestone, solid in the brick plant pit and irregular and nodular to the east, with the fossiliferous shale just above, would represent the Ewing limestone horizon, and the shales above used at these two plants would come near the Ames limestone in the horizon of the Birmingham shales.

Fourpole Creek Clays.—Southeast of Huntington, one mile out Eighth street across Fourpole creek, and on the hillside, there is a good exposure of five feet of white plastic clay that might be used for stoneware. A similar clay is seen one mile south on the hill above Hyser branch of Fourpole creek at the side of the road. At this point it appears immediately below a heavy sandstone (Connellsville). Next to the sandstone is a ten-inch layer of clay with numerous impressions of fossil leaves, black in color. A short distance up the hill this layer grades into the other clay below

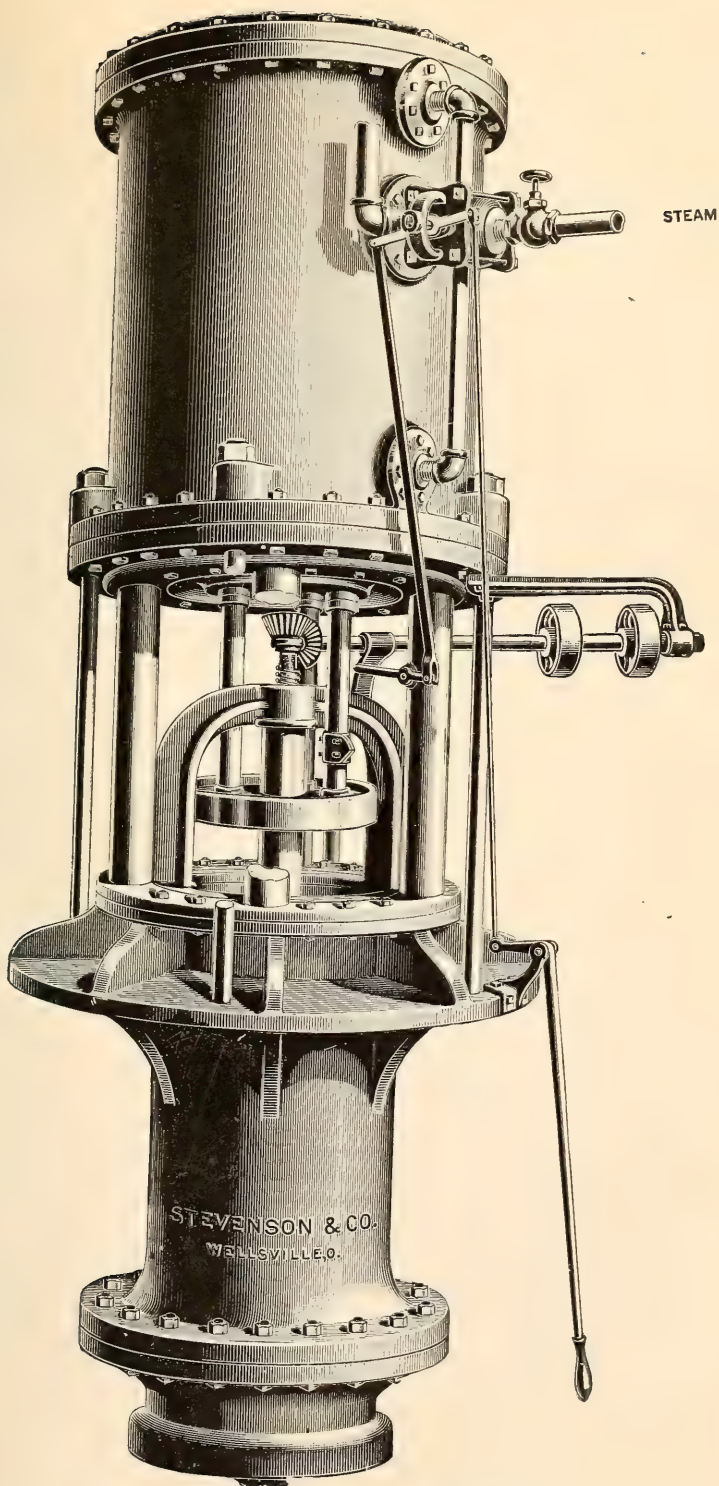


Plate XVI.—Stevenson Sewer Pipe Press.

it and here there are three and one-half feet of yellow sandy shale, then four feet of blue clay. The clay and sandstone above dip to southeast 36 feet in 300 to 500 feet.

The distance from these clays to the creek below is 120 feet, the interval containing sandy shales and sandstones. Up this branch of Fourpole creek, at a level 60 or 70 feet below the upper clay and sandstone level is a massive sandstone (Morgantown) with 15 feet of blue and red shales, folded and fractured, which would represent the horizon worked at the brick and tile plants three miles to the north. About three-quarters of a mile to southwest and 10 feet higher is a nodular limestone two feet thick with coal blossom below.

The order of these formations is given in the following section, which, however, is not in a single hill but over the area studied and would therefore not represent the proper intervals in the vertical section as the dip of the formations is omitted:

	Feet.	Inches.
Sandstone	10+	..
Buff shaly clay with fossil leaves.....	..	10
Shale, buff, sandy.....	3	..
Blue clay	4	..
Shales, sandstones	60	..
Sandstone, Morgantown	12+	..
Blue, compact shale	1	..
Blue and red shales	15	..

On the Bennett farm on the hill above the tile works, and 130 feet higher, a red shale has been opened by an open cut 30 feet long and eight feet deep, showing five feet of clay and shale.

Chemical Analysis.—The composition of this Bennett clay and the red and blue shales below the Morgantown sandstone on the Hyser branch of Fourpole creek are given below. The Bennett clay comes 30 or 40 feet above the Morgantown sandstone. The red and blue clays are intermingled and samples were selected of the pure blue layers and of the red layers. The analyses of these two shales show very little difference except in the higher percentage of ferric iron which gives the color to the red clay. The lime percentage is the highest found in any of the clays or shales examined. The Bennett farm clay is quite a pure clay and it will be of interest to compare its analysis with those of the lower shales used at the tile plant.

	Bennett farm. Shale clay.	Fourpole, Blue.	Shale. Red.
Silica	56.28	46.89	47.59
Alumina	22.81	18.04	16.51
Ferric iron	4.69	2.66	6.17
Ferrous iron	0.25	1.51	1.77
Magnesium	0.98	1.70	1.87
Lime	1.37	10.94	9.20
Sodium	0.16	0.36	0.45
Potassium	1.83	2.88	2.86
Water	4.07	2.52	2.53
Titanium	0.66	0.62	0.61
Phosphorus	0.21	0.44	0.62
Loss on ignition	7.16	11.65	10.36
	100.47	100.21	100.54

The mechanical analyses show the following percentages of different sized particles :

	Range in millimeters.	Bennett clay.	Four Pole Blue shale.
Fine clay	0.00 to .001	4.8	3.0
Coarse clay	0.001 to .005	7.0	4.8
Silt	0.005 to .02	34.7	15.6
Fine sand	0.02 to .15	23.7	10.7
Coarse sand	.15 to 2.0	25.8	29.2
Very coarse sand	2.0 to 6.0	....	34.2
Water		4.0	2.5

A rational analysis of the Bennett farm clay gives :

	Per cent.
Free silica	29.09
Feldspar	3.68
Clay substance	67.23

Physical Properties.—The Bennett clay slakes in three minutes, requires 27 per cent. of water to develop a normal molding consistency, has a maximum plasticity of 12, and air shrinkage of 8 per cent. Its average tensile strength is 212 pounds to the square inch with a maximum of 216 pounds. When the clay is weathered its tensile strength reaches 275 pounds. If dried rapidly, this strength falls to 84 pounds.

The Bennett farm clay begins to vitrify at cone 1 (2102° F.) and completed at cone 5 (2246° F.), with a fire shrinkage of 10 per cent. It is viscous above cone 10 (2426° F.), and a glass at cone 14 (2570° F.). The other clays become viscous at cone 1, (2102° F.), changing from dark red to black color, and represent very fusible clays.

This Bennett farm clay should prove valuable. It has a low percentage of chemical impurities and its physical properties are

very good. It is only opened in a small way so that with present information its extent and thickness are unknown.

Chemical Properties of the Huntington Tile and Brick Shales.—The blue shale above the limestone at the brick company pit east of Huntington, the red shales of the lower pit, and the yellow shales of the upper pit of the roofing tile plant show the following composition:

	Blue Shale. Brick Plant.	Red Shale. Tile Plant.	Yellow Shale. Tile Plant.
Silica	58.28	52.31	58.91
Alumina	21.26	22.31	20.00
Ferric iron	1.87	9.17	5.89
Ferrous iron	3.37	0.83	1.04
Magnesium	1.35	1.92	1.75
Lime	0.78	0.62	0.52
Sodium	0.39	0.44	0.58
Potassium	2.87	2.97	2.22
Water	1.30	1.58	1.79
Titanium	0.86	0.84	0.71
Phosphorus	0.39	0.28	0.64
Loss on ignition	6.84	6.56	5.82
	99.56	99.83	99.87

These shales are very similar in chemical composition except the variation in percentages of iron. The percentage of fluxes in the blue shale is 10.63; in the yellow shale, 11.00; and in the red shale, 15.95.

The red shale shows by rational analysis:

	Per cent.
Free silica	19.73
Feldspar	15.79
Clay substance	64.48

Physical Properties.—The blue shale requires 25 per cent. of water to develop its normal molding consistency; the red shale, 29 per cent.; the yellow shale, 27 per cent. The maximum plasticity of the three shales is 10; the air shrinkage of the blue shale is $4\frac{1}{2}$ per cent.; of the yellow, $3\frac{1}{2}$ per cent., and of the red shale, 8 per cent. The tensile strength of the blue shale is 78 pounds, with maximum of 84 pounds, or when weathered increases to 131 pounds to the square inch. The tensile strength of the yellow shale is 70 to 75 pounds, or when weathered 136 pounds. The red shale gives a tensile strength of 152 and maximum of 175, when weathered the strength increases to 208 pounds. These shales slake very slowly, the blue shale slaking more rapidly than the

other two. These tests show the great advantage of the weathering process.

The blue shale reaches incipient fusion at cone 1 (2102° F.) and is vitrified at cone 5 (2246° F.), with a fire shrinkage of 7 per cent. The red shale shows incipient fusion at cone 05 (1922° F.) and vitrifies at cone 1 (2102° F.), completed at cone 5 (2246° F.), with shrinkage of 10 per cent. The yellow shale is unaffected at cone 05 (1922° F.), but begins to vitrify at cone 1 (2102° F.) and complete vitrification is reached at cone 5 (2246° F.), with fire shrinkage of 12 per cent.

Barboursville and Ona, Cabell County.

At Barboursville, eight miles east of Huntington, and Ona, twelve miles east on the Chesapeake & Ohio railroad, thick deposits of sandy shales are found in the hills. The new brick plant at Barboursville is preparing to use these shales in manufacture of paving brick. These shales come in upper part of the Cone-maugh series, but their exact horizon was not determined.

Guyan Valley Brick Company.—This plant is located one mile southwest of the station at Barboursville, and was built in 1904. The machinery is housed in a large frame building compact in form so as to facilitate handling the clay and brick. The plant is on the Guyan Valley branch of the Chesapeake & Ohio railroad.

The equipment consists of a Steel disintegrator, two Frost nine-foot dry pans, ten-foot pug mill, and a Steel & Company auger machine of 70,000 brick capacity in ten hours. The brick are dried in two five-track National steam driers holding 85 cars with capacity of 54,000 brick. When the plant is fully completed it will have eight down-draft kilns, thirty feet in diameter, holding 70,000 brick each, and six up-draft kilns, 70 feet long, holding 400,000 brick.

Shale Pit.—Near the plant is a large acreage of sandy river clay which is opened eight feet in depth and borings show it to be 38 feet deep. This clay makes a very good grade of red building brick which will be burned in the up-draft kilns.

Across the railroad track and about one-eighth mile from the plant is a group of rounded hills made up of shale and sandstone layers. There are in the place selected for the quarry 30 to 40 feet of the buff shales.

Chemical Analysis.—The buff shales from this locality have the following composition :

	Per cent.
Silica	53.03
Alumina	22.14
Ferric iron	7.12
Ferrous iron	1.26
Magnesium	1.57
Lime	1.01
Sodium	0.29
Potassium	3.59
Water	1.94
Titanium	0.66
Phosphorus	0.79
Loss on ignition	6.56
	99.96

A rational analysis gives :

	Per cent.
Free silica	7.96
Feldspar	27.25
Clay substance	64.79

The shale is high in ferric iron and low in lime, so would burn to good red color. The proportion of fluxes is 14.84 per cent., very similar to the shales near Huntington.

Physical Properties.—The shale slakes very slowly and requires 25 per cent. of water to develop a normal molding consistency, the maximum plasticity is 15, and the air shrinkage $5\frac{1}{2}$ per cent. The tensile strength is 96 pounds with a maximum of 105, and when weathered, the tensile strength reaches 155 pounds.

Incipient fusion occurs at cone 05 (1922° F.), vitrification at cone 1 (2102° F.), completed at cone 5 (2246° F.), with 2 per cent. fire shrinkage.

Ona Shales.—Four miles east of Barboursville at the little station of Ona, the Chesapeake & Ohio railroad cuts expose 30 to 40 feet of shales. In the cut west of Ona station the following section is exposed :

	Feet.
Sandstone	5+
Buff shale with some blue shale.....	25
Sandstone	3
Buff shales to C. & O. track.....	10

In the cut one-half mile east of the station the following strata occur :

	Feet.
Buff shales	12
Blue clay	1—2
Buff shale, compact.....	2
Buff shales, with some Blue shale.....	15

These shales may be observed in a number of cuts in this region and have a large surface extent. Small iron concretions occur in the lower shales in the west cut.

Chemical Analysis.—The shales were sampled from the cuts east and west of Ona station and show the following composition:

	West Cut. Per cent.	East Cut. Per cent.
Silica	48.00	52.11
Alumina	25.29	23.92
Ferric iron	5.34	5.28
Ferrous iron	3.62	3.00
Magnesium	2.06	2.14
Lime	2.33	0.36
Sodium	0.26	0.29
Potassium	3.31	2.80
Water	1.60	1.61
Titanium	0.72	0.64
Phosphorus	0.32	0.47
Loss on ignition	7.41	6.91
	100.26	99.53

The shale has not changed much in composition in a half mile. The percentage of lime is higher at the west cut. The percentage of ferric iron should give the burned clay a good red color. When compared with the Barboursville and Huntington shales it is seen that all these shales are quite similar. The percentage of fluxes in these two shales is 16.92 and 13.87.

Physical Properties.—These shales slake very slowly and require about 25 per cent. of water to develop their normal molding consistency. The maximum plasticity of the shale in the west cut is 16, and in the east cut 11. The air shrinkage of both shales is about 6 per cent. The tensile strength of the shale in the west cut is 126 pounds with a maximum of 130, and when weathered reaches 168 pounds. The other shale has a tensile strength of 94 pounds and a maximum of 116 pounds, and when weathered reaches 134 pounds to the square inch.

In the west cut shale incipient fusion is reached at cone 05 (1922° F.), vitrification occurs from cones 1 to 5 (2102° F. to 2246° F.), with practically no shrinkage. In the shale from east cut there is no trace of fusion at cone 05 (1922° F.), but vitrification begins at cone 1 (2102° F.) with 11 per cent. fire shrinkage.

Clarksburg, Harrison County.

In addition to one plant using river clay, there are three brick plants near Clarksburg using shales. The shales at two of the plants come above the Pittsburg coal and therefore belong in the Monongahela series, while at the third plant the shales are below the coal and will be discussed at this place under the Cone-maugh series.

Monticello Brick Company.—The plant of this company is located one mile and a half south of Clarksburg on the West Virginia and Pittsburg branch of the Baltimore & Ohio railroad, and was opened in 1896.

The equipment includes a nine-foot dry pan, twelve-foot pug mill, Bucyrus auger machine of 40,000 capacity, though the daily output of the plant is 20,000 brick. The brick are dried in a four-track steam tunnel drier of 30,000 capacity and burned in four 15-arch up-draft permanent wall kilns, holding 175,000 brick each. The size of the brick made by this company is $8\frac{1}{2} \times 4 \times 2\frac{1}{4}$ inches. They are burned with gas and have a good red color.

Shale Pit.—A section of the shale pit a short distance back of the plant shows:

	Feet.
Light brown loess like clay.....	5 to 10
Buff clay in places weathering white.....	3
Dark brown and blue shales	15

The upper clay is quite sandy and has a very similar appearance to the loess clays of the Mississippi Valley and breaks in the same way in large more or less cubical or prismatic blocks through a pronounced vertical jointing. It has the appearance of being an alluvial or river clay deposited over the shale in this valley.

The brown and blue shales are intermixed and where weathered and bleached look almost like pure fire clays. Small, hard nodules like gravel in size are scattered through these shales. The bedding planes are crumpled forming in places minute folds. The upper loess like clay and the darker brown or buff clay below grade into each other and can only be separated in a few places. The change of color is probably due to weathering and water action. The vertical joint planes have a slight dip in different directions, many of them to the northeast.

The Pittsburgh coal is mined toward town and at the mine one-half mile north, the coal is 140 feet higher than the shale pit. The section of the hill one-quarter mile east of the shale pit shows:

	Feet. Inches.	
Sandstone quarry (<i>Gilboy</i>).....	25	..
Sandy shales and concealed.....	30	..
Sandstone	1	..
Sandy shales	30	..
Limestone		10
Sandy shales and concealed	135	..
Shales	35	..
Sandstone	6 to 10	..
Coal Pitcairn mine, <i>Pittsburg</i>	9	..
Shales sandy	80	..
Coal, <i>Clarksburg</i>	1	2
Shales	5	6
Limestone	4	..
Coal	0	6
Shales and concealed	30	..
Shales, Monticello pit.....	25	..

The horizon of these shales at Monticello plant is just below the Little Clarksburg limestone and above the Morgantown sandstone, which was not reached in this section, but should not be very far below the bottom of the shale pit.

Chemical Analysis.—In the manufacture of brick at the Monticello plant about two-thirds shale is mixed with one-third of the loess-like clay. An analysis was made of an average sample of the brown and blue shales with the following results:

Silica	49.69
Alumina	21.80
Ferric iron	4.25
Ferrous iron	1.43
Magnesium	1.45
Lime	5.35
Sodium	0.23
Potassium	3.00
Water	3.52
Titanium	0.72
Phosphorus	0.30
Loss on ignition	8.20
	99.94

The proportion of fluxes in this clay is 15.71 per cent. The lime percentage is higher than the ferric iron, but apparently does not alter the color given by the iron as the burned brick are a brownish red of good color.



Plate XVII-a.—Old Etna Upper and Lower Clay Mines, New Cumberland.

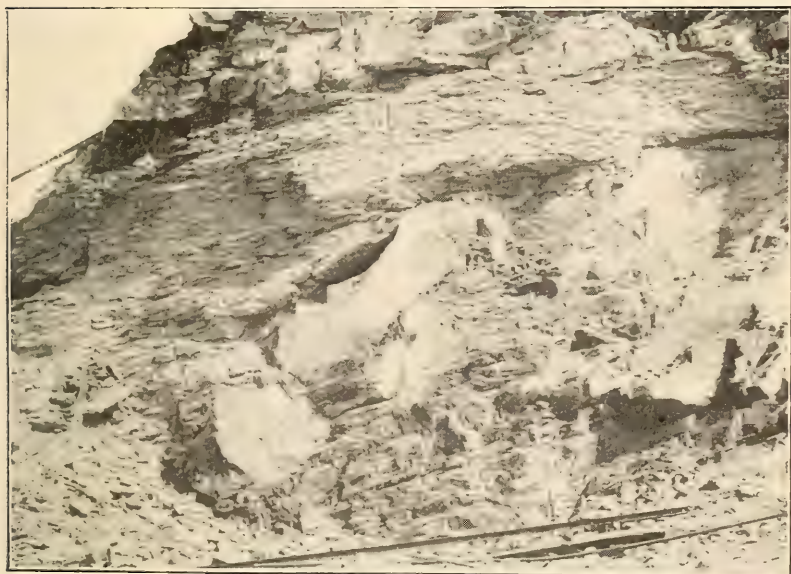


Plate XVII-b.—High Grade Brick Company, Shale Pit at Clarksburg.

A mechanical analysis shows the following :

	Range in millimeters.	Per cent.
Clay	0.00 to .005	3.9
Silt	0.005 to .02	8.2
Fine sand	.02 to .15	7.9
Medium sand	.15 to 1.00	63.6
Coarse sand	1.00 to 3.00	12.9
Water		3.5

The 12.9 per cent. on 3 millimeters screen was mostly flat scales of shale about 5 millimeters in size of red and greenish color.

Physical Properties.—The Monticello clay requires 21 per cent. of water to develop a normal molding consistency, its maximum plasticity is 18, air shrinkage 5 per cent., its tensile strength 50 to 60 pounds, or 83 pounds when weathered. Incipient fusion occurs at cone 05 (1922° F.), vitrification at cone 1 (2102° F.), with a fire shrinkage of 5 per cent., and it forms a glass at cone 14 (2570° F.).

Monongahela Series.

This series includes the formations from the base of the Pittsburgh coal to the top of the Waynesburg coal. The rocks found in the series are coals, limestones, sandstones, and shales. The order of the rock strata is well shown in the section¹ of Pinnickinrick hill or mountain at Clarksburg which rises 300 feet above the Pittsburgh coal.

	Feet.	Inches.	Feet.	Inches.
<i>Coal, Waynesburg</i> , absent or not seen concealed and yellow sandy shales.....	65	9	251	0
Sandstone	25	0		
Concealed with some limestone.....	80	0		
Sandstone	20	0		
Concealed	5	0		
Sandstone	15	0		
Sandy shales.....	6	0		
Sandstone, <i>Sewickley</i> ,.....	25	0		
Shales	10	0	1	0
<i>Coal, Sewickley</i> ,.....				
Limestone	9	0	40	0
Concealed	3	0		
Shales, sandy.....	14	0		
Shales, with iron nodules.....	1	0		
Shales, sandy.....	4	0		
Sandstone	1	0		
Concealed	8	0		

1. W. Va. Geol. Survey, Vol. II., p. 140.

<i>Coal, Redstone, slaty</i>			3	0
<i>Shale, dark, bituminous</i>	5	0		
<i>Limestone, Redstone,</i>	6	0		
<i>shale, greenish</i>	13	0	25	0
<i>Shale, bituminous</i>	1	0		
<i>Coal, Pittsburg</i>			8	6
			328	6

Clarksburg, Harrison County.

In addition to the plant described above, which works a shale below the Pittsburg coal in the Conemaugh series, there are two brick plants using the shales above the Pittsburg coal.

Clarksburg High Grade Shale Brick Company.—This plant is located one mile east of Clarksburg on the Baltimore & Ohio railroad, and was erected in 1895.

The equipment includes a Stevenson nine-foot dry pan, Raymond twelve-foot pug mill, Raymond stiff-mud brick machine (Daytonian) of 50,000 brick daily capacity, though the output at present is 20,000 brick, and a Raymond repress.

The brick are dried in a five-track steam tunnel drier holding 50 cars, with a capacity of 25,000 to 30,000 brick. They are burned in two down-draft modified Eu Daly kilns, 28 feet in diameter, holding 50,000 brick, and in three 18-arch up-draft kilns with a capacity of 200,000 brick each. Natural gas is used as fuel. The brick are red in color, and building, paving, and fire brick are made.

Shale Pit.—The shale pit is above the level of the plant and the shales are blasted out in open quarry, loaded in cars which pass down a slight incline to the mill. A section of the quarry shows:

	Feet.	Inches.
Cover of soil and clay.....	2	6
Coal <i>Redstone</i>	1	
Buff shale, sandy.....	9	
Fire clay, blue with lime nodules.....	10	
Buff shales.....	10	
Blue sandstone.....	0	10
Shales.....	1	
Coal, <i>Pittsburg</i>	9	

The upper coal (Redstone) and so called fire clay run out to the east end of the quarry, and are best seen at west end. At extreme east end of the quarry the fire clay comes in again, three feet thick. Plate XIX shows a view of the east end of this quarry with the Redstone coal near the top and the limestone nuggets piled in foreground.

The shales are finely laminated and a cross fracture shows alternate thin dark and light banding. There are traces of vertical jointing, but very irregular. The lime nodules in the fire clay are elongated and rounded, some measuring three feet across and they are often filled with bright particles of pyrites of iron. These nodules probably represent the Redstone limestone. The quarry face has a length of over 300 feet. The clay and shales are mixed and used for the brick. A small portion of the cover is also added. The fire clay and shales are shown in the lower part of plate XVII.

Chemical Analyses.—Analyses were made of the clay (which is high in lime for a fire clay) and also of the shales below the fire clay as follows:

	Shale.	Clay.
Silica	56.15	53.35
Alumina	23.48	24.78
Ferric iron.....	2.93	1.08
Ferrous iron.....	0.33	1.66
Magnesium	1.55	0.90
Lime	1.25	4.04
Sodium	0.49	0.24
Potassium	2.66	2.27
Water	1.74	1.23
Titanium	0.97	0.86
Phosphorus	0.38	trace
Loss on ignition.....	8.17	10.11
	100.10	100.52

These analyses show 9.21 per cent. of fluxes in the shale, and 10.19 per cent in the so-called fire clay, so that in reality the shale would be more of a fire clay than the clay, but neither would deserve this name. They will make a good building and paving brick as proved by the product made, but should not be used for fire brick where they are to be subjected to any high temperature. The red color of the brick is given by the shale mixture as the clay by itself would burn buff and the more shale used the better the red color given to the brick.

The shale and clay by mechanical analysis show the following range of particles:

	Range in millimeters.	Shale.	Clay.
Fine clay.....	0.0 to .001	7.0	5.0
Coarse clay.....	.001 to .005	7.8	4.1
Silt	.005 to .02	30.2	19.4
Fine sand.....	.02 to .15	8.2	8.7
Medium sand.....	.15 to 1.00	3.5	36.4
Coarse sand.....	1.00 to 4.00	41.6	25.2
Water		1.7	1.2

Physical Properties.—Both shale and clay slake readily; the water required to develop a normal molding consistency in the shale is 23 per cent., and in the clay 20 per cent.; the maximum plasticity of the shale is 16, and of the clay 20; the air shrinkage of the shale is 5 per cent; of the clay, 6 per cent.

The tensile strength of the shale is 132 pounds with a maximum of 155 pounds, when weathered it reaches 180 pounds to the square inch. The tensile strength of the clay is 157 pounds with a maximum of 168, and when weathered reached 218 pounds. If the clay is dried the tensile strength falls to 111 pounds.

The shale reaches incipient fusion at cone 1 (2102° F.) and is vitrified at cone 5 (2246° F.) with a fire shrinkage of 4½ per cent. The so-called fire clay begins to vitrify at cone 1 (2102° F.) and is completely vitrified at cone 5 (2246° F.), with a fire shrinkage of 8 per cent.

Glen Elk Brick Company.—The plant of this company is located across the track an eighth of a mile from the Baltimore & Ohio depot at Clarksburg, and was started in 1900, but has burned twice since that time, the last fire being in August 1904, and the plant was in process of rebuilding at close of the 1904 season.

The equipment consisted of Bucyrus machinery manufactured by the American Clay Working Machinery Company. It included a nine-foot dry pan, twelve-foot pug mill combined with the auger machine of 40,000 brick capacity, though only 15,000 brick were made daily. The brick were dried in a five-tunnel drier, one track to each tunnel, and burned in three up-draft permanent wall kilns holding 120,000 brick each.

Shale Pit.—The shale pit close to the plant shows a similar structure to the other plant, except the so-called fire clay is distributed through the shale and a ledge of limestone shows at the top of the section. The lime nodules occur through the shale.

Section.	Feet.
Soil and clay, cover.....	3
Limestone, <i>Redstone</i>	2
Shaly sandstone.....	3
Shales and clay.....	12
Coal, <i>Pittsburg</i>	9

Building brick only are made which have red color, and the twelve feet of shales and clay are used with a small amount of the shaly sandstone, which through weathering becomes a sandy shale.

Spilman, Mason County.

Camden Clay Company.—The plant of this company is located at Spilman, eight miles north of Point Pleasant on the Ohio river branch of the Baltimore & Ohio railroad. The plant was erected in 1897 and its equipment includes a Williams patent pulverizer, nine-foot Boyd dry pan, six-foot wet pan used for tile, pug mill, Chambers auger machine of 40,000 brick capacity, two double mold Eagle represses, 28,000 brick capacity each, a four-mold, Chisholm, Boyd, White dry press of 24,000 brick capacity, and a Murray tile machine with capacity 8,000 shingle tile daily which is not in use at the present time.

The brick are dried in a hot air drier with six double track tunnels with a capacity of 40,000 brick. There are ten down-draft kilns with eight fire holes each, 28 feet in diameter, and holding 45,000 to 48,000 brick. Coal fuel is used and four kilns draw into one stack which is partitioned. The paving blocks are burned from 11 to 14 days, and weigh before burning $12\frac{1}{2}$ pounds, and after burning $9\frac{3}{4}$ pounds; in size they average $9\frac{1}{4}\times4\frac{1}{8}\times3\frac{3}{8}$ inches.

While the company makes a specialty of paving blocks, they manufacture some building brick and occasionally dry press brick. They formerly made roofing tile shingles, but this work has not been carried on for the past four seasons. The brick are red in color, very hard, and stand high tests of crushing, absorption, and rattler.

Shale Pit.—The company formerly made red building brick and tile from a deposit of river clay near the works. The present shale pit was opened in 1901 and is located on top of the high hill just east of the plant. It is reached by a 1,500-foot incline, and is 260 feet above the brick plant. The shale is mined in open quarry, 28 feet high and hauled in cars to edge of hill where it is dumped into the long inclined chute and passed down to the crusher at the plant. The shales are much crumpled in places and the blue shale is filled with small lime nodules. The section of the hill is as follows:

	Feet.	Inches.	Feet.	Inches.
Soil and clay cover.....	2	0	26	8
Shaly sandstone.....	3	0		
Sandstone, buff.....	6	0		
Shales, buff or yellow (worked).....	9	0		
Limestone nodules.....	0	8		
Shales, blue.....	6	0		
Shales, sandy and concealed.....	27	0		
Sandstone.....	4	0		
Sandstone, shaly.....	9	0		
Red shales and clay.....	25	0		
Sandstone, shaly and clay.....	30	0	210	0
Red shales.....	7	0		
Coal bossom, faint.....				
Limestone, irregular.....	3	0		
Shales, sandstone, and concealed.....	80	0		
Sandstone, <i>Pittsburg</i>	15+			
Shales, finely laminated.....	10	0		
Coal, <i>Pittsburg</i>	6	0		
Sandy shales, and concealed to level brick plant.....	60	0		

Comparing this section with the one at Hartford, six miles northeast, as given in volume II. of the reports of this survey, page 142, the horizon of the shales worked at this plant would be about 50 feet below the Waynesburg coal, which is the top member of the Monongahela series. The shales have never been given any special name, but may be called the *Spilman shales*, as this is the only locality where they are used.

Chemical Analysis.—The average mixture of the blue and buff shales in this shale pit, and the buff shale, show the following composition:

	Mixture.	Buff shale.
Silica	50.80	55.29
Alumina	19.47	21.87
Ferrie iron.....	8.83	5.07
Ferrous iron.....	1.90	1.69
Magnesium	1.74	2.19
Lime	1.51	0.76
Sodium	0.89	0.55
Potassium	2.24	2.24
Water	0.60	1.76
Titanium	0.68	1.02
Phosphorus	0.20	0.60
Loss on ignition.....	11.37	6.34
	100.23	99.38

Physical Properties.—The buff shale requires 29 per cent. of water to develop a normal molding consistency, its maximum plasticity is 11, air shrinkage is $4\frac{1}{2}$ per cent. The tensile strength is 83 pounds, or when weathered 152 pounds. The shale is not

affected at cone 05 (1922° F.), but begins to vitrify at cone 1 (2102° F.), and is completely vitrified at cone 5 (2246° F.), with a fire shrinkage of 12 per cent.

Moundsville, Marshall County.

Suburban Brick Company.—The office of this company is located in Wheeling, but the plant is located one mile and a half northeast of Moundsville and was started in 1891, and purchased by present company in 1900.

The equipment includes a nine-foot Stevenson dry pan, pug mill, Arnold-Creager brick machine with daily capacity of 25,000 brick. There are two tunnel driers, one with four tracks and the other with ten tracks, giving a combined capacity of 60,000 brick. The brick are burned in one 20-arch up-draft kiln, holding 325,000 brick, and three 17-arch up-draft kilns holding 275,000 brick each. Coal is used for fuel, and building brick only are made.

Shale Pit.—The shale is mined in open quarry from the hill above the plant and hauled down an incline track in mine cars. The pit shows the following strata:

	Feet.	Inches.
Cover, soil and sandstone boulders.....	0	30
Coal (<i>Little Waynesburg</i>).....	0	10
Shale with irregular nodules of lime.....	10	0
Shale, buff, in thin layers.....	7	0
Sandstone	2	6
Shale, buff in thin layers.....	10	0
Black coal-like shale.....	0	2
Shale, breaks in blocks.....	15	0
Limestone floor.....	4	0
Blue shales.....	2+	

Less than a mile west the Pittsburg coal is mined in a shaft 160 feet deep, or about 250 feet below the base of this section. This distance would bring the coal of this section near the Waynesburg horizon and probably represents the Little Waynesburg coal. The shales would be near the horizon of those worked at Spilman.

Chemical Analysis.—The shale from this pit has the following composition:

	Per cent.
Silica	54.52
Alumina	23.23
Ferric iron.....	4.80
Ferrous iron.....	2.23
Magnesium	1.71

Lime	0.97
Sodium	0.53
Potassium	2.94
Water	1.84
Titanium	0.82
Phosphorus	0.13
Loss on ignition.....	5.97
	99.69

This shale burns red and has 13.18 per cent. of fluxing elements as compared with 17.11 per cent. in the Spilman shale.

Physical Properties.—The clay slakes very slowly; it requires 25 per cent. of water to develop a normal molding consistency; its maximum plasticity is 11; its air shrinkage is 4½ per cent. The tensile strength is 102 pounds with a maximum of 117 pounds to the square inch. If dried rapidly the tensile strength is 54 pounds.

Vitrification begins at cone 1 (2102° F.) and is complete at cone 5 (2246° F.), with a shrinkage of 12 per cent.

DUNKARD OR PERMO-CARBONIFEROUS SERIES.

This series includes the rocks above the horizon of the Waynesburg coal, and completes the section of the formations in West Virginia. The rocks are regarded by geologists as belonging to the Permian or closing division of the Carboniferous and therefore of the Paleozoic era. They cover a belt 40 to 60 miles in width bordering the Ohio river. At a number of places the shales and clays of this series might be utilized, but at the present time they are only used near Parkersburg at the roofing tile plant.

Parkersburg, Wood County.

United States Roofing Tile Company.—This plant, started in 1903, is located two miles east of Parkersburg. The equipment includes one nine-foot Raymond dry pan; a Raymond wet pan; an auger brick machine, with wires across the open die to cut the clay bar into thin plates which are cut in proper lengths by hand wire cut off; a Raymond hand power repress for flat tile; and a five die patent tile press. The tile are made in rounded form, so as to be laid on the roof with edges of one row of tile overlapping the edges of the next row.

The tile are dried on cast iron frames made in the shape of the tile, and they are dried in a four-track tunnel drier holding 44 cars. The tile are burned in saggars made of slabs of fire clay set up in square compartments in the kiln. The kilns, four in number, are of round down-draft type, 26 feet in diameter, and heated with gas fuel. The saggars hold fifteen tile each and the kiln holds 22,000 tile, seven and one-half by fourteen inches in size, and are burned in six to seven days.

The main building is brick, two stories high, with the machinery below, and a hand molding room above where ornamental tile, cresting, corners, etc., are made. A large one-story frame ware-room is used for storage of finished tile. The plant is close to the Baltimore & Ohio railroad main line east, and its capacity is 5,000 to 6,000 tile daily.

Shale Pit.—The shales used are brought in cars down an incline from the open quarry on the hill above the plant. A section of the pit shows:

	Feet.
Yellow sandy clays.....	4
Sandstone and sandy shales.....	10
Red shales.....	12

The company owns ten acres of these shales which are claimed to be 130 feet thick as tested. The tile is made from a mixture of one-half red shale and one-half sandy buff shale. Through these shales are numerous hard nodules. The shale pit is about 100 feet above the Marietta sandstone quarried near the creek level to the northeast.

Chemical Composition.—The red shale is probably similar in composition to the red shales farther south described above. The sandy shale has the following composition:

	Per cent.
Silica	68.42
Alumina	16.38
Ferric iron.....	3.05
Ferrous iron.....	1.89
Magnesium	1.80
Lime	0.94
Sodium	0.63
Potassium	0.93
Water	0.00
Titanium	0.88
Phosphorus	0.08
Loss on ignition.....	4.58
	99.58

CHAPTER IX.

THE RIVER CLAY INDUSTRIES OF WEST VIRGINIA.

A large number of the brick plants in this State secure their clay from banks near creeks or rivers. Such clays are often quite sandy and are only adapted to the manufacture of common building brick. The clay is ploughed or removed by pick and shovel without blasting. As the deposits are numerous and widely distributed the plants can be located near towns and railroads, at the same time being close to the deposits. Nearly all of the smaller plants depend on these local deposits for their supply. The clay is worked by the soft mud process, molded by hand or machines of simple construction.

ORIGIN OF THE CLAYS.

Through the northern portion of the United States there are extensive deposits of glacial clays formed through rock erosion by large ice sheets in recent geological time, in the Glacial period. In this State there are no clays formed by the direct action of ice erosion, as the lower limits of the great glaciers were to the north, but there are extensive deposits of clay formed through the indirect action of these former glaciers.

It is not the province of this report to give a detailed account of this glacial history which is to be found in other places, but an outline of this history will be given to illustrate the origin of some of the river clays of this State.

The careful study of the stream valleys by geologists has proved almost beyond question that the courses of the rivers in this section were different before the Glacial period, from the present. At that time the Ohio river did not exist, and the drainage of the southern part of this State was to the west to about

the position of the present Ohio and thence northwest across Ohio. The northern drainage along the Monongahela valley was north to Pittsburg and to the present site of Lake Erie. The streams thus flowed north and northwest.

As the great glacier moved down from the north across the present Great Lakes area, it cut off the outlets of these rivers with a wall of ice and rock debris, the waters were thus dammed back filling the river valleys almost, if not quite, to their sources. The waters spread out between the walls of the valleys, forming lakes of quiet water with small currents, in which were deposited sediments from the surrounding hills and from the melting ice.

One of these lakes occupying the valley of the Monongahela, lower Allegheny, and upper Ohio basins has been named by Dr. I. C. White, Lake Monongahela.¹ The water would rise until it found a gap in the surrounding hills through which it could escape. In the Monongahela lake this gap seems to be located near Salem on the present line of the Baltimore & Ohio railroad from Grafton to Parkersburg. The overflow passing through this gap gradually lowered the waters. With the outflow at this point a current would be formed in the lake thus carrying the sediment from the north through the whole valley. The fine grained clays adapted to brick and pottery manufacture are now found in this valley 100 to 150 feet above the present river. The terraces representing long continued water levels are marked topographical features today in this valley and the various towns are located on them.

At this same time similar changes were taking place in the southern valleys. The ancient Kanawha river was flowing through the Teays valley to Huntington and thence to the northwest through a river named by Tipton,² the Marietta river. When the ice sheet closed the outlet of this river, the waters were held back, forming a lake similar to the northern one, which may be called Lake Kanawha.

In this basin were deposited the fine grained, banded, Teays clays, 20 to 50 feet in thickness. The rising water in this lake

1. Amer. Geol. Vol. 18, p. 368; 1896.

2. U. S. Geol. Survey, Profess. Paper No. 13.

finally flowed out through a gap to the northwest and reached the Marietta river at Pt. Pleasant, a course which it has followed from that time, leaving the Teays valley below St. Albans.

The ice barrier at the north and northwest across Ohio prevented the outflow of the rivers in that direction, so the accumulating waters passed to the east and south. The rivers in the valley of the present Ohio near Huntington and Pt. Pleasant cut their way backward, removing the barriers near Crown City and Gallipolis until they united, forming the early Ohio river, which by further deepening of its channel and backward cutting and meandering toward Pittsburg, finally tapped the Monongahela waters and established the Ohio drainage system nearly as at the present time.

This is the generally accepted explanation of the origin of these clays in the Monongahela, Teays, and adjacent valleys, though Campbell, in the Charleston and Huntington folios of the U. S. Geological Survey has given a theory of origin of the Teays valley clays as due to local ice dams formed near Ashland, Kentucky, and Milton, West Virginia. While these clays are not utilized to any extent, they are fine grained plastic clays of good quality and would be adapted to several lines of clay products.

In addition to these clays of indirect glacial origin, there are extensive deposits along the valleys of the various rivers and smaller streams which have been deposited by the streams under ordinary conditions. These alluvial clays represent sediments brought from upper portions to lower levels where the velocity of current is much diminished. They occur in the river channel and are spread over the flood plains above the usual water level.

All of these clays belong to the group of transported clays and were not originally formed in the place where now found. They will contain the components of the various rocks from which they are derived and will therefore be more or less impure. They are frequently very sandy, with boulders, fine and coarse material intermingled, and they vary in composition and character in the different parts of the deposit. This group of clays is used in many places in the State, but the plants using river clays are generally small.

DESCRIPTION OF BRICK PLANTS AND CLAY DEPOSITS.

OHIO RIVER VALLEY.

Barboursville, Cabell County.

S. D. Hughes Brick Yard.—This plant is located three-fourths mile southwest of town on the Guan river branch of the Chesapeake & Ohio railroad, and was opened in 1903.

The brick are molded in a Horton soft mud machine of 20,000 capacity, operated by horse power. The brick are dried on pallets in twenty-two rack driers, each holding 1,260 brick. There are two temporary wall, scove up-draft kilns, one with nine arches holding 140,000, and one with eleven arches, holding 175,000. Wood and coal fuel are used. Common red building brick are made and sold for local use.

The Guyan Valley Brick Company erected a plant in 1904, one-eighth mile from the Hughes yard and make common building brick from a similar clay, and also make paving brick from shale in the hills above.

Clay Pit.—The clays used are yellow sandy clays found in the valley and represent ordinary alluvial clay. The deposit is six to eight feet deep with ten feet at least of blue clay below, which is said to burn buff and is not used at the present time. The clay is ploughed and tempered in a small soak pit.

Chemical Analysis.—The buff and blue clays have the following composition:

	Buff clay.	Blue clay.
Silica	69.74	64.65
Alumina	14.86	18.74
Ferric iron.....	4.75	1.74
Ferrous iron.....	0.55	2.20
Magnesium	0.81	0.82
Lime	0.36	0.36
Sodium	0.42	0.41
Potassium	2.36	3.06
Water	0.99	1.52
Titanium	0.97	0.68
Phosphorus	trace	0.16
Loss on ignition.....	4.61	5.59
	100.42	99.93

A mechanical analysis shows the following range of particles:

	Range in millimetres.	Buff clay. Per cent.	Blue clay. Per cent.
Fine clay.....	0.00 to 00.1	21.0	16.4
Coarse clay.....	.001 to .005	13.0	7.0
Silt	.005 to .02	32.0	53.0
Fine sand.....	.02 to .15	22.0	17.0
Coarse sand.....	.15 to 1.00	11.0	5.0
Water		1.0	1 6

Physical Properties.—The buff clay slakes in one minute, the blue, in a half minute. The water required to develop an average molding consistency is 28 per cent. for the buff and 25 per cent. for the blue clay. The maximum plasticity of the buff is 18, and of the blue 11. The air shrinkage in both clays is about 5 per cent. The average tensile strength of the buff clay is 201, with a maximum of 235 pounds. In the blue the average is 152 and maximum 163 pounds to the square inch.

The buff clay reaches incipient vitrification at cone 1 (2102° F.) and is completely vitrified at cone 5 (2246° F.) becoming a glass at cone 14 (2570° F.). Its fire shrinkage is 11 per cent.

The blue clay is vitrified at cone 1 (2102° F.) and is a black glass at cone 10 (2426° F.). Its fire shrinkage is 5 per cent.

Charleston, Kanawha County.

Neale-Morrow Brick Company.—This plant is located three miles west of Charleston at the station of Patrick, on the Kanawha & Michigan railroad, and was started sixteen years ago.

The clay is molded in a Kell soft mud auger machine with capacity of 30,000 a day. The brick are dried in a hot air tunnel drier with nine tracks, giving a capacity of 50,000 brick. There are three up-draft kilns with eighteen arches, each holding 300,000 to 348,000 brick. There is one furnace to three arches, built out from side of kiln for use of coal, though for the past few years gas fuel has been used. There is also one down-draft kiln not in use. Six to eight feet of alluvial sandy clay are worked in pits near the plant, and its characters are similar to those farther up the Kanawha river which will be described in the next section.

Kanawha Brick Company.—At the plant of this company, one mile east of town on the Kanawha river, ten feet of river clay are worked, as well as the hard clay from the hills above. The equipment of the plant has been described in the preceding chapter with a description of the hillside clays. The river clay has been used since 1897 in the manufacture of red building brick and is burned in three up-draft kilns.

This company has another yard on Elk river, one mile from Charleston, which was started by Mr. Isaacs seventeen years ago. The clay is ground in a Potts crusher, tempered in a twelve-foot pug mill and molded on an auger machine of 40,000 capacity, making 25,000 brick daily. The brick are dried in an eight-track steam tunnel drier, holding 72 cars, with 45,000 capacity. The brick are burned in one down-draft kiln, 28 feet in diameter, holding 60,000, and three up-draft kilns, 21 arch, holding 360,000 each, and burned with gas.

The river clay is 15 feet thick in this pit and is hauled in cars by cable to the plant. The first paving brick probably used in the United States were made from the Kanawha Valley river clays at a point further down the river, by Mr. Isaacs.

Chemical Composition.—The clay from the Kanawha Brick Company yard on Kanawha river above Charleston, and the yard on Elk river were analyzed, showing the following composition:

	Kanawha yard.	Elk yard.
Silica	66.89	71.02
Alumina	14.52	13.65
Ferric iron.....	5.20	4.69
Ferrous iron.....	0.59	0.42
Magnesium	0.72	0.84
Lime	0.48	0.59
Sodium	0.71	0.40
Potassium	2.53	2.19
Water	1.54	1.15
Titanium	0.77	0.80
Phosphorus	1.09	0.28
Loss on ignition.....	4.74	4.23
	98.78	100.26

Mechanical Analysis.

	Range in millimetres.	Kanawha yard.	Elk yard.
Fine clay.....	0.00 to .001	6.5	14.9
Coarse clay.....	.001 to .005	10.0	5.0
Silt	.005 to .02	46.0	38.0
Fine sand.....	.02 to .15	32.0	34.0
Coarse sand.....	.15 to .50	4.0	7.0 (to 3.00 mm.)
		1.5	1.1

These clays burn red on account of their high percentage of ferric iron. While the samples are taken from places two miles apart, they show but slight variation, and the analyses probably represent a fair average composition for the Great Kanawha river alluvial clays.

Physical Properties.—The Kanawha yard clay slakes in one minute and the Elk clay in a half minute. Both require 28 per cent. of water to develop a normal molding consistency. The maximum plasticity of the former is 13, and of the Elk clay, 16. The air shrinkage is $4\frac{1}{2}$ to 5 per cent. The tensile strength of the clay at Kanawha yard is 155 pounds with a maximum of 166. In the Elk yard clay the average tensile strength is 112 pounds with a maximum of 125 pounds.

The clay from the Kanawha yard reaches incipient fusion at cone 1 (2102° F.) and is almost viscous at cone 5 (2246° F.). Its fire shrinkage is 8 per cent. The clay from the Elk yard reaches incipient fusion at cone 1 (2102° F.), and complete vitrification at cone 5 (2246° F.), and is viscous at cone 10 (2426° F.). Its fire shrinkage is 7 per cent.

Buff Building and Fire Brick Company.—This plant is located about two miles east of Charleston on the Kanawha river, and was started in 1903. At the present time they use the river clay, making red building brick. The clay is tempered in a pug mill and molded in an auger machine of 25,000 capacity. The brick are dried in the open yard and burned in three up-draft kilns with eleven, eighteen and twenty-two arches holding 155,000, 285,000 and 350,000 brick. The clay is similar to that of the Kanawha yard and the company owns a tract of buff burning clay in the hills south of the plant, which they plan to use.

Culloden and Milton, Cabell County.

W. H. McAllister Brick Works, located at east end of the town of Culloden, was started in 1896. The equipment includes a Horton soft mud machine, thirteen rack pallet drying sheds, each with a capacity of 3,600 brick, two up-draft kilns holding 150,000 to 260,000 brick, three twenty-foot round down-draft kilns for drain tile. Coal fuel is used and the color of brick and tile is light red.

Clay Pits.—To the east of the plant is a fine grained, banded clay exposed to a depth of twelve feet in the pit and represents the Teays valley clay of indirect glacial origin. This clay is used at the plant for drain tile. To the west of the plant is a large acreage of buff, sandy clay used for brick. The clay has a similar appearance to the other river clays of this region as worked farther west at Milton.

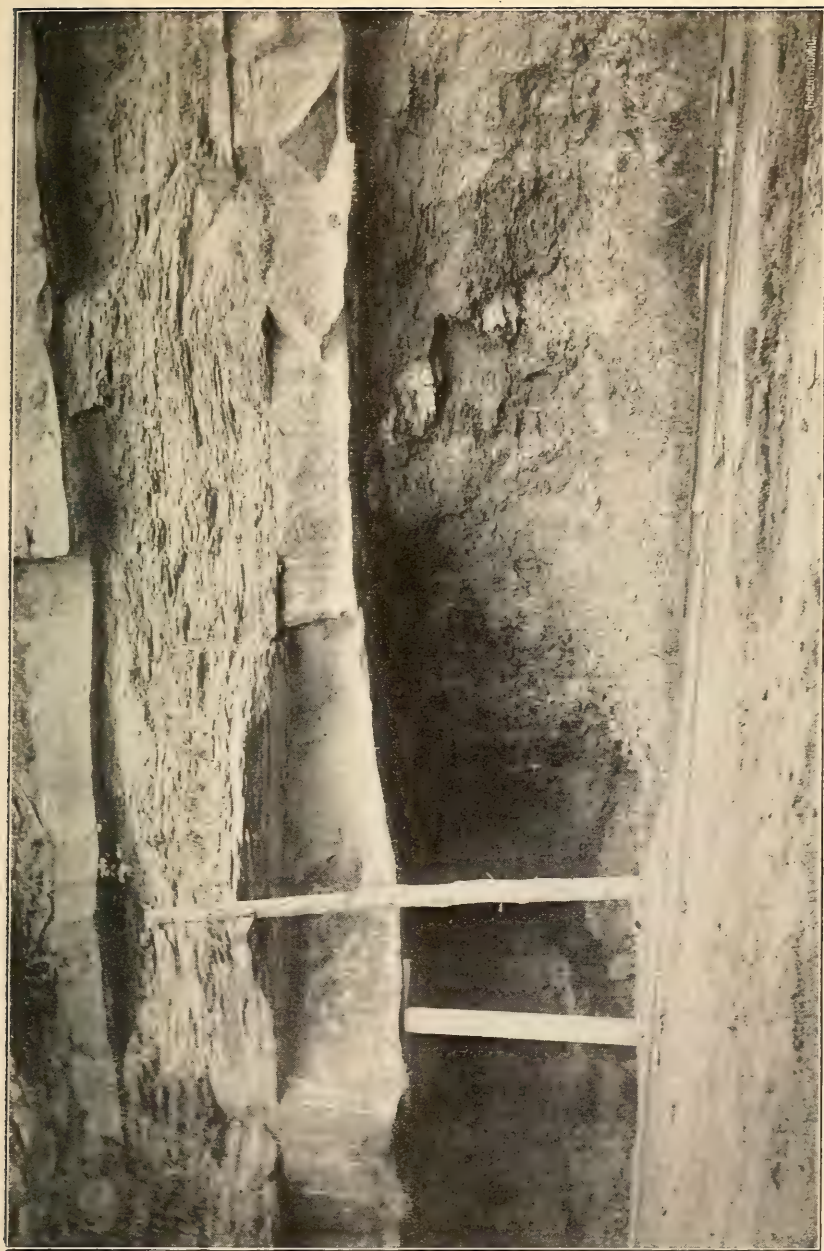


Plate XVIII.—Kanawha and New River Brick Company Clay Mine at Charleston.

Heck & Sons' Brick Company.—This plant is located at the east edge of the town of Milton, four miles west of Culloden, on the Chesapeake & Ohio railroad. It was started as the Kane yard about 1890 and has been operated by the present company since 1901.

The clay is tempered and molded in a Wellington soft mud machine of 20,000 capacity. The brick are dried in an eleven track hot air tunnel drier holding 45,000 brick, which are burned in three sixteen-arch up-draft kilns holding 350,000 to 450,000 and burned with gas.

The clay used is a river clay, sandy in character. A section of the pit shows eight feet of yellow clay with three feet of blue clay below, and burns to a deep red color.

Chemical Analyses.—The banded Teays clay from Culloden and the buff sandy clay from Milton have the following composition:

	Culloden clay.	Milton clay.
Silica	52.89	68.94
Alumina	26.56	15.13
Ferric iron.....	4.95	2.90
Ferrous iron.....	0.59	1.35
Magnesium	1.38	0.95
Lime	0.48	0.80
Sodium	0.20	0.96
Potassium	3.12	2.24
Water	1.93	1.00
Titanium	1.00	0.93
Phosphorus	trace	trace
Loss on ignition.....	7.34	5.31
	100.44	100.51

Mechanical Analyses.

	Range in millimetres.	Culloden.	Milton.
Fine clay.....	0.00 to .001	39.6	12.05
Coarse clay.....	.001 to .005	23.0	13.00
Silt	.005 to .02	31.0	36.90
Fine sand.....	.02 to .15	2.0	25.65
Coarse sand.....	.15 to 5.00	2.4	11.40 (to 3.00)
Water		2.0	1.00

The brick at Milton yard are deeper red than the drain tile at Culloden on account of higher temperature of burning as the iron percentage is higher at Culloden. The sandy character of the Milton clay is shown by these analyses.

Physical Properties.—The Culloden clay slakes in five minutes and the Milton in one-half minute. The former clay re-

quires 30 per cent. of water to develop a normal molding consistency and the latter 23 per cent. The maximum plasticity of the Culloden clay is 7 and its air shrinkage is 8 per cent., while the Milton clay reaches 19, and has a shrinkage of $4\frac{1}{2}$ per cent. The tensile strength of the Milton clay is 120 pounds with a maximum of 165, and in the Culloden clay is 170 pounds with a maximum of 182 pounds to the square inch.

The Culloden clay, which is typical of the Teays valley clays, becomes nearly steel hard at cone 05 (1922° F.). Incipient fusion begins at cone 1 (2102° F.), and vitrification is complete at cone 5 (2246° F.). The color changes from red to black on vitrification and the fire shrinkage is $15\frac{1}{2}$ per cent.

The Milton clay shows no change at cone 05 (1922° F.) with incipient vitrification at cone 1 (2102° F.) and complete vitrification at cone 5 (2246° F.). Its fire shrinkage is only 1 per cent.

Huntington, Cabell County.

Huntington Red Brick Company.—This plant is located at Central City, three miles below Huntington, and was started as a hand yard in 1890.

In the lower yard the brick are molded on an Arnold-Creager soft-mud machine with a capacity of 40,000, run at 20,000. The brick are dried in eight rack sheds on pallets with 81,000 brick capacity, and sixteen sheds with 110,000 capacity. There are two up-draft kilns holding 250,000 brick each, and one up-draft kiln holding 300,000.

In the upper yard a Hercules soft-mud machine made by Horton Company, of 40,000 capacity is used, and 20,000 brick made daily. A Sharer hot air furnace drier is used with 40,000 capacity. There are two up-draft kilns, 18 arches holding 250,000 brick. The brick are burned five days with gas and then five days with coal. This yard was started in 1902 under the name of Huntington Brick Company and was consolidated with the other yard early in 1904. Eight to nine feet of sandy river clay are used at both plants and obtained from nearby pits. The brick are of good red color.

Point Pleasant, Mason County.

Mountain State Brick and Tile Works.—This plant was started in 1896 by the present owner, C. L. Hess, just above the

town. The equipment includes a Freese crusher and auger of 40,000 capacity, and 28,000 brick are made a day. The brick are dried in open sheds holding 90,000, and the Scott car system of filling and unloading the sheds is used. There are two up-draft kilns of 300,000 brick capacity each, and a down draft kiln, which holds 75,000 brick or 50,000 drain tile. The tile are made from 2½ to 12 inches in diameter, and both brick and tile are of good red color. They are used for local use and shipped to other points along the Kanawha and Michigan railroad.

The clay is a river clay with sand pockets in it and covers probably forty acres in this section and has a depth in the pit now worked of 13 feet. A similar clay was worked across the Kanawha river by Major James Smith for drain tile from before the war until 1893. Faite machinery was used and the works are still standing.

Chemical Analyses.—The following analyses were made of the river clay used at the Hess yard, and of the shale (not used) on the hill above near the B. & O. station

	Hess Clay.	Shale.
Silica	65.97	56.48
Alumina	16.61	21.77
Ferric iron.....	4.84	4.78
Ferrous iron.....	0.42	2.61
Magnesium	0.53	2.10
Lime	trace	0.72
Sodium	0.63	0.46
Potassium	2.17	3.00
Water	2.04	1.72
Titanium	0.78	0.83
Phosphorous	0.06	0.04
Loss on ignition.....	5.60	6.00
	99.65	100.51

When the analysis of this river clay is compared with those farther up the Kanawha at Milton and Charleston, it is found to agree very closely.

Physical Properties.—The Hess clay slakes in one-half minute and requires 32 per cent. of water to develop a normal molding consistency. The maximum plasticity is 14. The tensile strength is 183 pounds with a maximum of 205. This clay has a red color but is not affected at cone 05 (1922° F.). Incipient vitrification begins at cone 1 (2102° F.), and is complete at cone 5 (2246° F.), with a fire shrinkage of 8 per cent.

Ravenswood, Jackson County.

Keller Brick Yard, is located at the east end of town and was started in 1899. About 12,000 brick are made a day, and burn red in color. The equipment consists of a Freese auger machine of 30,000 capacity with combined pug mill. There are two up-draft kilns, ten and fifteen arches, holding 125,000 and 240,000 brick which are burned with wood and coal. The river clay is worked to a depth of 15 feet and is reddish in color, streaked with blue.

Parkersburg, Wood County.

Copen Brick Works.—This plant started in 1868, is located at the foot of Twelfth street, Parkersburg, a short distance from the Ohio river.

The clay is tempered in a nine-foot pug mill and molded in a Bucyrus auger machine of 40,000 capacity, though only 25,000 brick are made a day. No crushers or dry pans are used. There is a Raymond repress, but not in use. The brick are dried on pallets in open sheds, using the Scott car system. There are eighteen sheds, giving a drying capacity of 150,000. A hot air dry house of 52,000 capacity is used in winter or bad weather. It requires about one week to dry the brick in the open sheds, and forty-eight hours in the hot air shed.

The brick are burned in five up-draft kilns holding 210,000 to 300,000. The furnaces are built out from the sides of the kiln, one to three arches, and at present time gas is used. The clay is obtained from a large pit a short distance back of the plant, hauled in cars upon an incline track to the auger machine. The pit shows 18 feet of clay, which is along Pond creek, a small stream flowing into the Ohio. This clay is buff, fairly compact and uniform, with streaks of blue through it, and burns to a red brick.

O. O. Tolles Brick Company.—This plant is located a short distance above the Copen yard and was formerly known as the Riverside Brick Company. It has been idle for a few years but was reopened in 1904.

The clay is molded in a Freese auger machine of 40,000 capacity with pug mill combined, and the average daily output is 22,000. The clay is crushed in a disintegrator, and a Raymond repress is installed but not used. Gas fuel is used throughout the

plant. The brick are dried in an eight-track hot air tunnel drier with 60,000 capacity. They are burned in two round down-draft kilns, 30 feet in diameter, holding 65,000, and two fifteen-arch up-draft kilns of 200,000 capacity.

The clay pit is close to the mill and worked to a depth of 15 feet. In character the clay is similar to the Copen clay, burning to a deep red or brown color.

Parkersburg Brick Works.—This plant was started in 1900 as a hand mold yard and machinery installed in 1902. It is located east of town one and one-half miles out the Staunton pike.

The equipment consists of a Freese auger of 50,000 capacity, disintegrator, pug mill, and an eight-tunnel hot air drier of 30,000 capacity. The brick are burned in eight round down-draft kilns, 26 feet in diameter, holding 60,000 brick each, and in one fifteen-arch up-draft kiln of 200,000 capacity, using gas fuel.

The clay pit is located in the bend of Washington creek and worked nearly to water level, showing 12 feet of soft red clay which is hauled in dump cars by cable up an incline to the mill. Twenty feet above this clay and near the mill is a deposit of eight feet of buff loam clay, formerly worked in hand molds, but now abandoned. The brick made from the lower clay burn to a deep brown color, or with less heat to a reddish brown and are used for building brick.

Chemical Analyses.

	Copen Yard.	Parkersburg Brick Works.
Silica	70.00	63.88
Alumina	13.70	17.18
Ferric iron.....	4.53	5.72
Ferrous iron.....	0.42	0.50
Magnesium	0.94	1.30
Lime	0.38	0.16
Sodium	trace	0.60
Potassium	2.97	2.29
Water	0.97	1.76
Titanium	0.79	0.87
Phosphorous	0.37	0.36
Loss on ignition.....	4.77	5.60
	99.84	100.22

Physical Properties.—The Copen clay slakes in one minute, requires 27 per cent. of water to develop a normal molding consistency, reaches maximum plasticity of 18, air shrinkage of $4\frac{1}{2}$

per cent., average tensile strength of 200 pounds and a maximum of 222.

The Parkersburg Brick Works clay slakes in a half minute, requires 32 per cent. water for normal molding consistency, maximum plasticity 13, air shrinkage 6 per cent., tensile strength 140 to 150 pounds to square inch.

The Copen clay is unaffected at cone 05 (1922° F.), reaches incipient vitrification at cone 1 (2102° F.), and is vitrified at cone 5 (2246° F.), with a fire shrinkage of 9 per cent. Its color changes from red to a brownish gray. The Parkersburg Brick Company clay shows the same temperature changes as the Copen clay, but changes from red to a black color with a fire shrinkage of 12 per cent.

Mechanical Analyses.

	Range in millimetres.	Copen Clay.	Parkersburg Brick Works.
Fine clay.....	0.00 to .001	16.6	25.2
Coarse clay.....	.001 to .005	11.0	12.5
Silt	.005 to .020	31.2	46.6
Fine sand.....	.020 to .150	29.7	11.3
Coarse sand.....	.15 to 2.000	10.5	2.7 (to 5.0)
Water		1.0	1.7

Harrisville, Ritchie County.

Harrisville Brick Company was started in 1902 by Davis & Patton, and burns a deep red building brick, made from a buff river clay worked to a depth of three feet. The brick are molded on a Steele & Sons' auger machine of 15,000 capacity, though only 7,000 to 9,000 are made daily. The brick are dried in sheds holding 35,000 and in open yard, and burned with gas fuel in one up-draft kiln holding 196,000.

New Martinsville, Wetzel County.

Magnolia Brick Company.—This plant is located one mile east of New Martinsville on the Baltimore & Ohio Short Line railroad, and was started in 1892, one-half mile west, moving to the present location in 1903.

The clay is molded in a Hercules machine of Horton Company with capacity of 40,000, run at half its capacity. The brick are dried in an eight-tunnel steam drier with capacity of 32,000, using the Scott car system. There are three temporary fifteen-arch up-draft kilns holding 180,000 brick each, burned with gas.

The river clay at pit shows 25-foot face. It is tough, brownish in color, somewhat jointed, with streaks of gravel through it. The pit is just above the level of a small stream. The chemical composition is given in connection with the next clay.

Clarksburg, Harrison County.

Clarksburg Brick Works were started in 1891 and operated since 1893 by J. M. Coffman. The clay is run through a Potts crusher, pug mill, and a Hercules soft-mud machine of 50,000 capacity. An automatic sander is used for mold boxes, but before 1903 the brick were molded by hand.

The brick are dried on steel pallets placed on a heated brick floor holding 13,000, the present capacity of the plant. There are three kilns holding 150,000 brick each, burned in ten days with gas fuel.

Clay Pit.—The river clay rests on the Clarksburg limestone and has two feet of soil cover. The deposit is eight feet in thickness with the upper four feet containing numerous sandstone fragments from pebbles to two feet in diameter. The water of Elk creek nearby is but little below the bottom of the pit. Across the creek the clay is 15 feet thick and has been worked to a small extent. These clays burn red and are used for common building brick.

Chemical Composition.—The following analyses show the composition of the Clarksburg and New Martinsville river clays:

	New Martinsville, Magnolia Works.	Clarksburg, Coffman Works.
Silica	65.35	73.46
Alumina	15.47	12.29
Ferrie iron.....	6.48	3.90
Ferrous iron.....	0.29	0.33
Magnesium	0.63	0.95
Lime	0.23	0.28
Sodium	0.71	0.41
Potassium	2.59	1.57
Water	2.08	1.78
Titanium	0.84	0.74
Phosphorous	0.31	0.59
Loss on ignition.....	4.93	4.26
	99.91	100.56

Mechanical Analyses.

	Range in millimetres.	New Martinsville.	Clarksburg.
Fine clay.....	0.00 to .001	16.2	14.2
Coarse clay.....	.001 to .005	7.3	4.0
Silt	.005 to .020	32.1	24.0
Fine sand.....	.020 to .15	35.6	34.0
Coarse sand.....	.15 to 2.00	6.7	22.0 (to 5.0)
Water		2.1	1.8

Physical Properties.—Both clays slake in one minute, require about 25 per cent. of water to develop the normal molding consistency, and have an air shrinkage of $4\frac{1}{2}$ per cent. The maximum plasticity of the New Martinsville clay is 11, and of the Clarksburg, 20. The tensile strength of the former is 190 to 200 pounds, and of the latter, 180 to 185 pounds.

The clay from New Martinsville reaches incipient vitrification at cone 1 (2102° F.) and complete vitrification at cone 5 (2246° F.) with a fire shrinkage of 8 per cent. and change of color from red to dark gray. The Coffman clay is steel hard at cone 1 (2102° F.) and vitrified at cone 5 (2246° F.) with a fire shrinkage of 7 per cent. The clay becomes viscous at cone 14 (2570° F.)

Philippi, Barbour County.

Philippi Brick and Tile Works.—This plant is located three-fourths mile southwest of town on the Baltimore & Ohio railroad, and was started in 1902. The equipment includes pug mill, auger machine of 35,000 capacity, seven-track tunnel drier, three fourteen-arch up-draft kilns and one twenty-four arch up-draft kiln, burned with gas.

The clay pit is a few hundred yards back of the plant and the clay is hauled up an incline track to the upper part of the building. The pit shows nine to eleven feet of brownish, sandy river clay with streaks of white clay.

The upper four feet of clay is loamy in character, breaking irregularly, then two feet of white, compact sandy clay separated from the lower compact brown clay, three feet in thickness, by a pronounced iron streak. The lowest bench is a white sandy clay of loose texture and with prismatic jointing. Iron streaks are common in upper part of the clay, and small sandstone fragments are found, also coal like fragments. The top of the clay rises rapidly as it is followed back to the hills. The Mahoning coal is mined 30 feet above the clay at a number of places.

Holt Brick Yard, is located three-fourths mile north of town and was started in 1876 nearer town and moved to present location in 1887. The brick are molded in an upright Penfield soft-mud machine, and 6,000 are made a day, using horse power. The brick are dried in open yard in summer or under roof in winter, and are burned in two up-draft kilns holding 33,000 and 126,000.

The clay pit shows four feet of river clay worked and is ten feet or more in total thickness. It has a reddish color except 18 inches of buff clay at the top and is sandy in character. Building brick of red color are made at the present time.

Weston, Lewis County.

Weston Brick Works.—This plant is located about two miles southwest of town and was built in 1900. The clay is molded on a Martin soft-mud machine of 35,000 capacity, and about 15,000 are made a day. A Martin crusher and pug mill are used for preparing the clay before molding. The brick are dried in a seven-track hot air tunnel, holding 40,000 brick, and are burned ten days in three up-draft 12-arch kilns holding 175,000 each.

Clay Pit.—The river clay is obtained in pits back of the plant and hauled in dump carts. The bottom of the pit is about twenty feet above the river, and the section shows two and one-half feet of red clay with six feet of yellow or buff sandy clay above covered with one foot of soil.

In making the brick the yellow and red clays are mixed in equal proportion and some surface soil added. The mixture burns to a brownish red color and makes a good common building brick. These clays are found in nearly all the valleys of this section and under the town of Weston.

Chemical Analyses.

	Yellow clay.	Red clay.
Silica	75.01	69.67
Alumina	12.15	15.45
Ferric iron.....	3.65	3.61
Ferrous iron.....	0.23	0.50
Magnesium	0.68	0.92
Lime	1.45	0.14
Sodium	0.15	0.36
Potassium	1.39	1.40
Water	1.45	2.00
Titanium	0.55	0.95
Phosphorous	trace	trace
	100.61	99.53

The yellow clay by rational analysis shows :

Free silica.....	57.20	per cent.
Feldspar	6.00	" "
Clay substance.....	36.80	" "

Mechanical Analyses.

	Range in millimetres.	Yellow clay.	Red clay.
Fine clay.....	0.00 to .001	15.85	20.75
Coarse clay.....	.001 to .005	11.00	12.10
Silt	.005 to .020	23.80	28.25
Fine sand.....	.020 to .15	28.10	32.70
Coarse sand.....	.15 to 4.00	19.80	4.20 (to 1.00)
Water		1.45	2.00

The yellow clay slakes in thirty seconds and requires 23 per cent. of water to develop a normal molding consistency. It is unaffected at cone 1 (2102° F.) and is vitrified at cone 5 (2246° F.), becoming viscous at cone 14 (2570° F.) Its fire shrinkage is 9 per cent.

The red clay is unaffected at cone 05 (1922° F.), reaches incipient vitrification at cone 1 (2102° F.) and complete vitrification at cone 5 (2246° F.) with a fire shrinkage of 10 per cent. It is viscous at cone 10 (2426° F.)

Fairmont, Marion County.

Hutchinson-Barnes Brick Company—This plant started in 1894, has been operated by the Hammond Brick Company since 1892. It is located one mile west of town on the county road.

The equipment includes a Hercules soft-mud machine made by the Horton company with 45,000 capacity, though the daily output at this plant is 25,000. The brick are dried in an eleven-track tunnel drier with 60,000 capacity, and burned in four up-draft kilns, one holding 325,000, the others, 275,000 brick. The river clay is used, which has an average thickness of ten feet and a maximum of twenty, and burns red.

Colfax, Taylor County.

The Colfax Brick Works was started in 1899. The brick are made on a Freese Union machine, with a capacity of 25,000, and 10,000 are made daily. The brick are dried in a three-track tunnel drier with a capacity of 20,000, and burned in three up-draft kilns holding 200,000 each. The plant formerly used the river clay, but now use shale which runs twenty-five to thirty feet in thickness.

Morgantown, Monongalia County.

Morgantown Brick Works.—This plant is located across the river at Morgantown and was started in 1891. The equipment includes a Horton soft-mud machine of 50,000 capacity, and a seven-foot Stevenson dry pan. The brick are dried on a heated floor and burned in five square up-draft kilns, each holding 200,000. The clay is worked to a depth of ten to fifteen feet along the bank of the river. It is sandy in character and burns to a red color.

Randall Brick Yard.—This yard is located three miles below Morgantown on the Baltimore & Ohio railroad. The equipment consists of a Wellington soft-mud machine of 40,000 capacity, and 20,000 are made daily, a roll crusher, and four steam tunnel driers with a capacity of 22,000. The brick are burned in four 14-arch up-draft kilns each holding 180,000 brick. The clay pit near the plant has 6 to 16 feet of river clay which burns to a red color.

Buckhannon, Upshur County.

Groscup Brick Yard, started in 1890, is located at west edge of town. The brick are molded by hand, the clay being tempered in a vertical pug mill and dried by hot air in a shed room holding 6,500 brick. There are three up-draft kilns, each holding 150,000 and burned with gas.

The river clay pit is about fifty feet from the river, and bottom of pit is 10 to 15 feet above water level in the river. The sandy clay has a thickness of 15 feet. This clay is found through the river valley and was worked a number of years ago by two other yards but they have been abandoned. The Groscup plant makes a million brick a year, sold to local trade. The brick are deep red color and of good quality for common builders. The chemical composition of this clay will be given in the next section.

Kingwood, Preston County.

Kingwood Brick Company, located at east edge of town. The clay is crushed in a Martin roll crusher, tempered and molded in a Kell combined pug mill and auger machine of 25,000 capacity. The drying floor is covered with steam pipes across which the green brick are piled. There is one nine-arch up-draft kiln, hold-

ing 60,000 brick, burned with coal. The plant has not been in operation for two seasons.

The clay bank just back of the plant shows five feet of buff sandy clay with white streaks. Similar clay is found in the other valleys of this section and is adapted to the manufacture of common brick, though the brick made at this plant were poorly burned and of low value.

Chemical Analyses.

	Buckhannon.	Kingwood.
Silica	78.12	66.08
Alumina	11.55	16.15
Ferric iron.....	3.23	5.75
Ferrous iron.....	0.34	0.37
Magnesium	0.40	0.87
Lime	0.26	0.17
Sodium	0.14	0.31
Potassium	1.32	2.43
Water	0.78	1.17
Titanium	0.46	0.80
Phosphorous	trace	0.17
Loss on ignition.....	3.50	5.64
	100.10	99.91

Mechanical Analyses.

	Range in millimetres.	Buckhannon.	Kingwood.
Fine clay.....	0.00 to .001	13.45	21.6
Coarse clay.....	.001 to .005	8.50	10.1
Silt	.005 to .020	23.90	30.0
Fine sand.....	.02 to .150	34.05	20.9
Coarse sand.....	.15 to 1.000	20.10	15.2 (to 3.0)
Water		0.80	1.1

Physical Properties.—The Groscup clay at Buckhannon slakes in a half minute, requires 23 per cent. of water to develop a normal consistency, has a maximum plasticity of 10, air shrinkage of $4\frac{1}{2}$ per cent., and a tensile strength of 86 to 88 pounds.

This clay is nearly steel hard at cone 1 (2102° F.), reaches incipient vitrification at cone 5 (2246° F.), and is completely vitrified at cone 10 (2426° F.), becoming a black glass at cone 20 (2786° F.) Its fire shrinkage is 8 per cent.

The Kingwood clay slakes in three minutes, requires 26 per cent. of water to develop a normal molding consistency, has a maximum plasticity of 21, air shrinkage of 4 per cent., and a tensile strength of 120 to 130 pounds to the square inch. The clay is apparently unaffected at cone 05 (1922° F.) and is nearly steel hard at cone 1 (2102° F.). It is vitrified at cone 5 (2246° F.), with a fire shrinkage of 10 per cent.

POTOMAC VALLEY.

While alluvial clays are found through the valleys of the Potomac drainage area, they have not been utilized for brick manufacture in many places. Some of these clays have been used in past years for stoneware, but the works have been discontinued.

Ridgely, Mineral County.

Ridgely Brothers' Brick Yard is located on the bank of the Potomac river, one-half mile southeast of town and across from Cumberland. The plant was started in 1892 to manufacture common red building brick.

The equipment includes a Talcott soft-mud machine of 25,000 capacity, though the capacity of the plant is 12,000 a day. The brick are dried in the open yard and burned in three up-draft kilns holding 200,000 each. The clay is taken from the bank of the Potomac and is very sandy near the river, but less so farther back. The two kinds of clay are mixed in the manufacture of brick. The clay rests on a gravel floor, and sand pockets occur through it.

Brant Brick Yard, located near the Ridgely yard, was opened in 1896 but has been idle for two seasons. This is a hand yard and the brick are dried in a shed by steam and burned in three up-draft kilns, holding 160,000 to 200,000. River clay similar to the last is used.

B. R. Valentine Yard is located a little nearer town and was opened in 1890, but has been idle since 1902. The equipment includes a Talcott soft-mud machine, four up-draft kilns holding 190,000 brick each. The clay was brought from farther down the river.

Chemical Analysis.—The river clay at Ridgely Brothers' yard shows the following composition:

Silica	74.86
Alumina	11.01
Ferric iron.....	5.31
Ferrous iron.....	0.18
Magnesia oxide.....	0.29
Lime oxide.....	0.40
Sodium	trace
Potassium	1.54
Water	1.07
Titanium	0.76
Phosphorous	0.44
Loss on ignition.....	4.07

 99.93

Physical Properties.—The clay slakes in one minute, requires 19 per cent. of water to develop a normal molding consistency. The plasticity is 17, air shrinkage $3\frac{1}{2}$ per cent., tensile strength 83 pounds to square inch, or when weathered reaches 99 pounds. Rapid drying did not injure its strength. The clay was unaffected at cone 1 (2102° F.) and was nearly steel hard at cone 5 (2246° F.) with a fire shrinkage of 4 per cent.

Martinsburg, Berkeley County.

There are extensive deposits of river clays in Berkeley county which to the eye have a similar appearance. One of these deposits, eight feet in thickness, was sampled on the Snyder farm near Snyder's Mill, a few miles from Martinsburg, and other extensive deposits are found near town. In order to show the composition of these clays near town, a sample was taken from the Welschance farm and the analysis is given below:

Chemical Analysis.

	Snyder.	Welschance.
Silica	70.41	60.23
Alumina	10.20	18.98
Ferric iron.....	7.11	6.07
Ferrous iron.....	0.45	0.39
Magnesia oxide.....	0.58	0.86
Lime oxide.....	0.50	0.56
Sodium	0.37	0.53
Potassium	1.73	3.06
Water	1.82	2.37
Titanium	1.20	0.89
Phosphorous	0.26	0.12
Loss on ignition.....	5.05	6.28
	99.68	100.34

Physical Properties.—The Snyder clay slakes in two minutes, requires 29 per cent. of water to develop a normal molding consistency. Its plasticity is 16, air shrinkage 5 per cent, tensile strength 151 pounds, or when weathered reaches 170 pounds. Rapid drying did not injure the tensile strength.

The clay is nearly steel hard at cone 05 (1922° F.), reaches incipient vitrification at cone 1 (2102° F.), and is completely vitrified at cone 5 (2246° F.), with a fire shrinkage of 10 per cent.

In addition to the plants described in the preceding sections of this chapter, there are small yards near Alderson, Monroe county, and North Caldwell, Greenbrier county.

CHAPTER X.

PHYSICAL TESTS ON WEST VIRGINIA BUILDING AND PAVING BRICK.

G. P. Grimsley and F. F. Grout.

The analyses and physical tests of the West Virginia clays as given in preceding chapters, show that the clays of this State are equal in quality to those found in other states whose clay product output is much larger. The equipment of most of the plants will enable the companies to manufacture products of as high quality as those of other states. It will therefore be a matter of interest to see how some of these West Virginia clay products compare with those regarded as standard in other sections, and these practical tests as applied to building and paving brick form the subject matter of this chapter. The tests and a large part of the description of the tests and results have been made by Mr. Grout.

In order to attain comparative results with the tests of different workers over the country, standard methods must be adopted, and the standard methods now in use are the results of careful discussion and experiments made under the direction of the National Brick Makers' Association. This organization after a number of years' work has adopted a set of standard tests which are in general use in city and private testing laboratories. Many of the larger companies have now installed testing apparatus where they investigate the character of their product before placing it before city engineers. They can thus locate any faults or defects and correct them.

A study of the results of tests over the country made by the uniform methods will show the contrast and similarity of products and lead to important practical results. One such result, for example, is the value of repressing paving brick. This method of manufacture certainly improves the appearance of the brick

and was generally thought to increase its strength, but a study of tests shows that in many clays the resulting brick is injured in strength by repressing. An effort has been made in the present study to make the results of scientific value in the general investigation of clays in this country, and at the same time furnish information about the quality of the clay products of the State.

It is not practical to test in the laboratory all kinds of clay wares. Pottery is tested by use, and cannot be sold by applied tests. The pottery must establish its reputation before the trade. The laboratory tests are usually confined to brick, and while there exists some difference of opinion as to the value of such tests, and while in some cases wrong conclusions, as to the value of the brick are drawn from tests, the worth of careful and uniform tests properly interpreted is generally recognized. Among the tests applied some are more important than others and all should not be given equal weight in forming conclusions as to the value of a certain brick submitted for use. In city work trained engineers should be employed for testing materials of construction, who can form a correct verdict from the facts revealed by tests.

PAVING BRICK.

Some years ago the crushing test was considered the most important test for paving brick, but now it is seldom applied in city awards. The rattler test is now regarded as the all important one in many cities, and when properly made is probably the most important as its action corresponds more closely to the wear on a street than any other.

The paving brick industry is an important one at a number of localities in this State, and the industry started here, so that for a number of years West Virginia was the leading State in this manufacture. Its rank at the present time is low and adjoining states have a far greater output. The causes of this condition are not easily explained, since there are large and numerous deposits of clay and shale adapted to this work, fuel cheaper and more abundant than in many of the large paving brick centers, and the brick made has stood the most severe tests and has given good results in actual use. Poor markets for paving brick are cited as one cause, but eastern city markets are available and brick is shipped to Philadelphia and farther east.

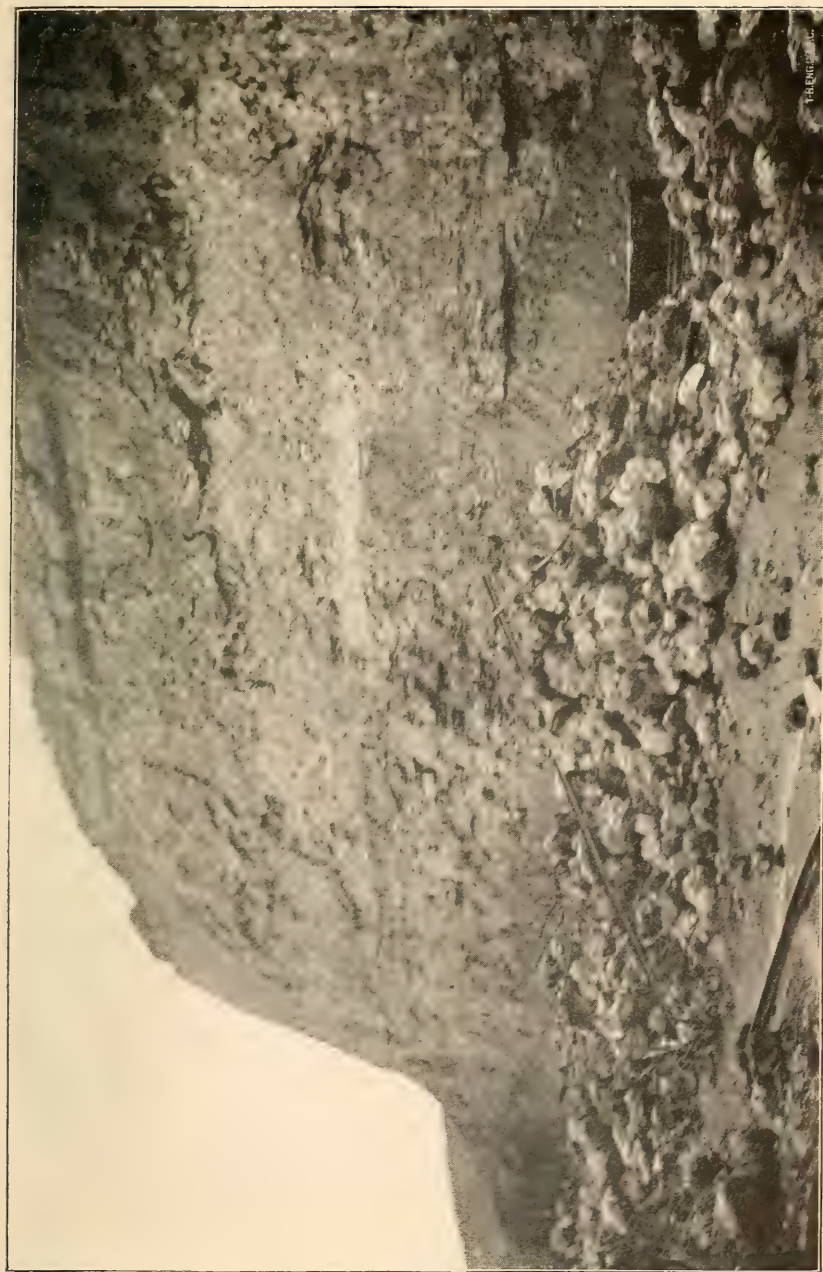


Plate XIX.—High Grade Brick Company Pit, Showing Coal, Clay, and Shale, Clarksburg.

The home market is not as large as it should be and many of our cities are afflicted with rough and muddy streets while the local brick plant is over stocked with brick. The advantages of brick pavements over other forms of pavement are numerous, and prominent among them are cheapness of cost and construction combined with marked durability.

BUILDING BRICK.

Building brick is one of the most popular forms of structural materials. It is permanent and can be made in various shades and shapes. The qualities required in a durable brick are difficult to measure by uniform tests and very few specifications have been adopted for their use. The city of New York, through its building department, has issued a set of specifications for building brick to be used in that place. The tests there recommended are the only ones, so far as we are aware, that have been stated in detail. However, it must be remembered that very few buildings have ever collapsed on account of the poor quality of the brick used. Where such accidents have occurred, the trouble has been due to faulty construction. The collapse of one of the large brick buildings in New York city which resulted in the formulation of the building brick specifications was found to be due to the freezing of the mortar in the foundation wall before it had set.

The pressure at the base of the very tall buildings is said to be about 157 pounds to the square inch,¹ and practically all building brick will greatly exceed this figure. Some specifications have been made which require the brick to withstand a pressure twenty times the strength actually necessary, and with this requirement, over half the building brick made in West Virginia would be accepted, and the other brick would not fall far short.

Fire brick and tile are sometimes tested for strength and the former for its refractory character, but no specifications have been adopted for uniform requirements, as these would vary with the use.

METHODS OF TESTING BRICK.

Rattler Test.—This test is a measure of the abrasion of the brick rolled in a barrel of special construction with a certain

1. Wisconsin Geol. Survey, Bull. IV.

weight of cast-iron shot. The results are stated in terms of the per cent. of loss in weight of the brick. It is applied to any brick which are to be subjected to abrasion in use, chiefly paving brick.

The rattler method has been modified from time to time. It was first recommended by the N. B. M. A. that the charge for the rattler should consist entirely of brick, a method later modified so that the charge in the present specifications consists of a smaller number of brick with a definite weight of cast-iron shot. The method proposed for lining the rattler with brick under investigation, and then adding a charge of shot which would abrade the edges of the brick with an action similar to the wear on a street, was proposed, but after careful consideration by the N. B. M. A. was rejected.

N. B. M. A. Specifications.

The uniform method of testing paving brick as adopted by the National Brick Makers Association is given below:

1. Dimensions of Machine.—The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling chamber.

Other machines may be used, varying in diameter between 26 and 30 inches, and in length from 18 to 24 inches, but if this is done, a record must be attached to the official report. Long rattlers must be cut up into sections of suitable length by the insertion of an iron diaphragm at the proper point.

2. Construction of the Machine.—The barrel may be driven by trunnions at one or both ends, or by rollers underneath, but in no case shall a shaft pass through the rattler chamber. The cross-section of the barrel shall be a regular polygon, having fourteen sides. The heads shall be composed of gray cast-iron, not chilled nor case-hardened. The staves shall preferably be composed of steel plates, as cast-iron ultimately breaks under the wearing action on the inside. There shall be a space of one-fourth of an inch between the staves for the escape of the dust and small pieces of waste.

Other machines may be used having from twelve to sixteen staves, with openings from one-eighth to three-eighths of an inch between staves, but if this is done a record of it must be attached to the official report of the test.

3. Composition of the Charges.—All tests must be executed on charges containing but one make of paving material at a time. The charge shall be composed of the brick to be tested and iron abrasive material. The brick charge shall consist of that number of whole bricks or blocks whose combined volume most nearly amounts to 1,000 cubic inches, or 8 per cent. of the cubic contents of the rattling chamber. (Nine, ten or eleven are the number required for the ordinary sizes on the market.) The abrasive charge shall consist of 300 pounds of shot made of ordinary machinery cast-iron. This shot shall

be of two sizes, as described below, and the shot charge shall be composed of one-fourth (75 pounds) of the larger size and three-fourths (225 pounds) of the smaller size.

4. Size of the Shot.—The larger size shall weigh about $7\frac{1}{2}$ pounds and be about $2\frac{1}{2}$ inches square and $4\frac{1}{2}$ inches long, with slightly rounded edges. The smaller size shall be $1\frac{1}{2}$ -inch cubes, weighing about seven-eighths of a pound each, with square corners and edges. The individual shot shall be replaced by new ones when they have lost one-tenth of their original weight.

5. Revolutions of the Charge.—The number of revolutions of the standard test shall be 1,800, and the speed of rotation shall not fall below 28 nor exceed 30 per minute. The belt power shall be sufficient to rotate the rattler at the same speed, whether charged or empty.

6. Condition of the Charge.—The bricks composing the charge shall be thoroughly dried before making the test.

7. The Calculation of the Results.—The loss shall be calculated in percentages of the weight of the dry brick composing the charge, and no result shall be considered as official unless it is the average of two distinct and complete tests, made on separate charges of brick.

The method as given above was used in the work of the Survey, and two separate tests were made on each sample lot of brick. The rattler was made at a local foundry from plans made by Mr. Grout and conforming to the specifications, but it was found advisable to use rolled steel staves instead of iron.

In making rattler tests on paving brick according to these specifications, the percentage of loss ranges from 11 to 35. The usual city specifications require this loss to be low, 20 or even 18 per cent. Brick have been used with good results whose loss in the rattler exceeded these figures. In the tests made on West Virginia paving brick the amount of loss ranged from 16 to 34 per cent., but in the latter case a defective lot of brick were tested in order to see how high a loss might result. It is sometimes of interest and value to determine the losses at various stages in the process, which will show whether the loss is due mainly to the first chipping off the edges of the brick or to a continuous wear on all surfaces as the test is continued. The losses at different stages in the process are shown by the curves in figure 20 which give the results of seven tests.

The application of rattler tests by the brick manufacturer enables him to determine whether his clay will make a better brick at certain temperatures over others. He thus finds in some cases that the so-called over-burned brick is an improvement over what had been called properly burned. Some of the building brick makers would find by these tests that their brick by proper burn-

ing could be used as pavers. The building brick from one company, when tested, showed only 19 per cent. loss in rattler.

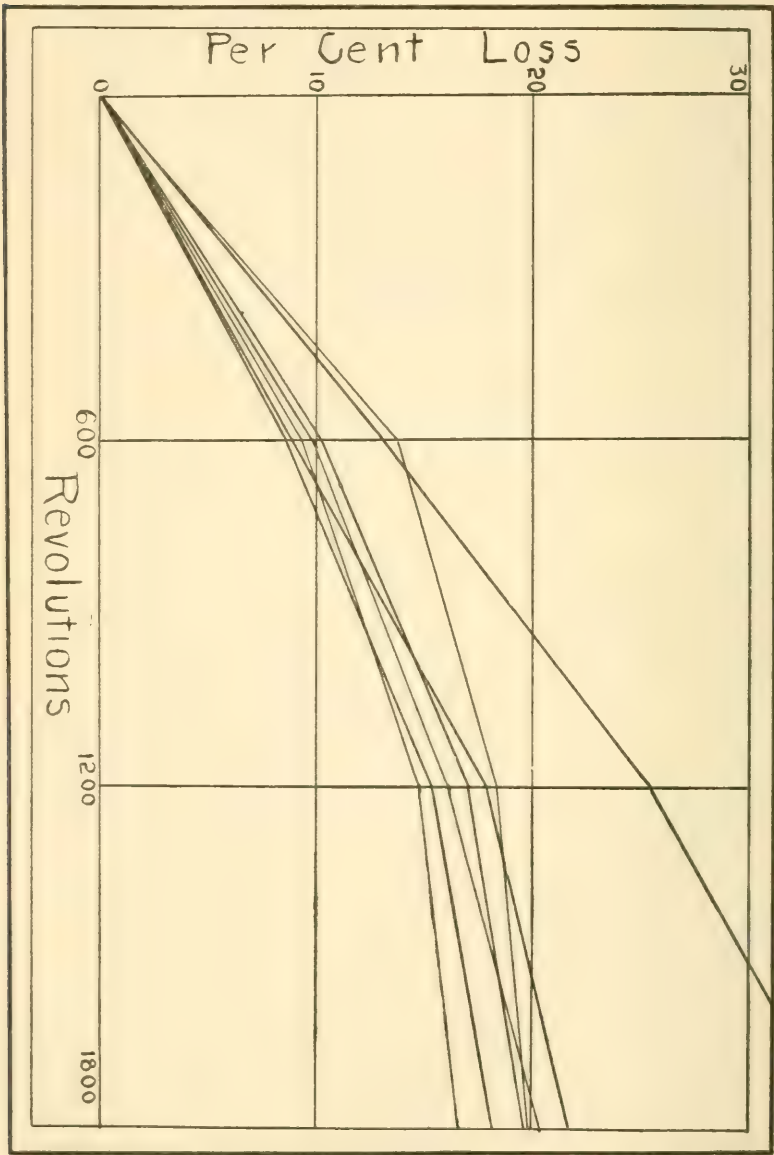


Fig. 20—Rattler tests on paving brick from seven West Virginia plants.

Transverse Test.—Transverse breaking tests are readily made when the proper machine is available and is often important in showing the quality of the brick by the nature of the fracture. The results are stated in terms of pounds per square inch, or the modulus of rupture.

The Survey tests were made on a Riehle machine of 50,000 pounds capacity at the mechanical laboratory of the University of West Virginia. The brick were supported on edge in the position they would be laid. The brick were tested in various positions and the results plotted in curves as shown in figure 21. A study of this figure shows that the results were but little changed by the position of the brick.

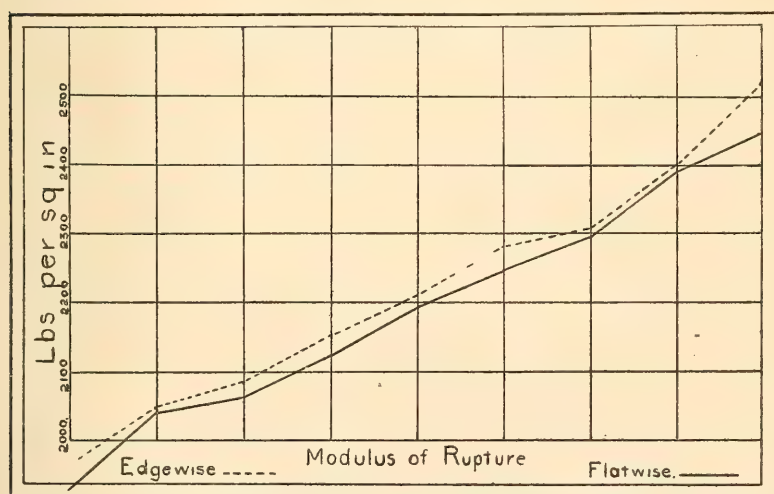


Fig. 21—Transverse tests on a sample lot of nine building brick.

In making the transverse tests, the supporting knife edges were six inches apart and were rounded to a radius of $\frac{1}{8}$ inch, slightly raised at the center of the knife to compensate for any warping of the brick. The upper knife edge was applied half way between the lower two. Ten or more brick of a kind were tested to secure average results. Figures 21 and 26 illustrate how a sample lot of brick supposed to be uniform, will vary in this test. There appears to be a fairly close agreement between transverse and crushing tests as shown in figure 22.

The modulus of rupture was calculated by the formula :

$$m = \frac{3 w l}{2 b d^2}, \text{ in which}$$

m =modulus of rupture,

w =the breaking load,

l =distance between the supports (6 inches).

b =width of the brick,

d =thickness of the brick.

The value of m is stated to range from 500 to 800, in common building brick. In the building brick of this State the modulus of rupture varied from 518 to 1,920; fire brick, from 193 to 300; paving brick, from 1,870 to 2,570. In a few cases a clearly marked shell appeared in the outer portion of the brick, probably formed by the repress which had altered merely the surface layers of the clay, leaving the interior with its original structure, thus developing possible planes of weakness, though the break rarely followed these planes or those of the auger structure when this appeared. Some common brick broke near nodules of sand and iron, showing the necessity of their removal from clays in the manufacture of strong brick.

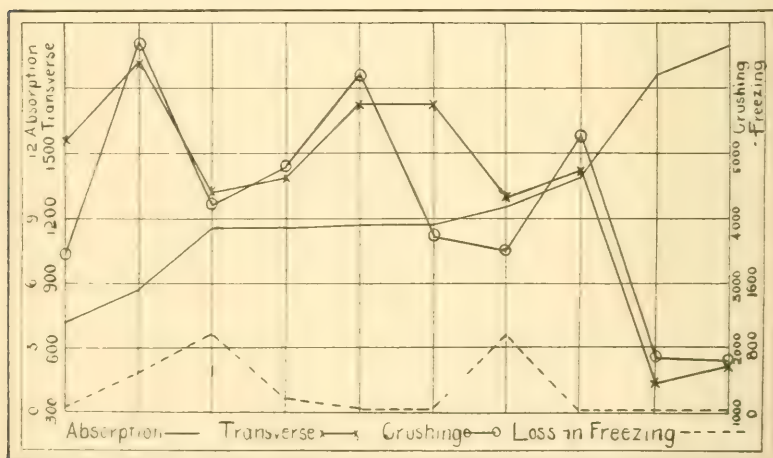


Fig. 22—Per cent. of absorption and tests of strength in pounds per square inch, in one diagram for comparison.

Crushing Test.—The crushing test some years ago was one of the most popular tests for building materials and is still looked upon with favor in some sections. Any good brick will withstand

the pressure applied to it in the wall or pavement. Brick after long exposure to weather and the action of micro-organisms is said to become weaker, but it is doubtful whether a brick which has a high crushing strength will withstand these destructive forces better than brick which crush more easily.

Crushing tests have been made in the present work to determine the effect of weathering in the following manner: The half bricks resulting from the transverse test were used to furnish cubes for the crushing test. Four faces of the cube represented the original brick surface while the other two were ground down to form a nearly perfect cube with its dimensions equal to the original thickness of the brick. The cube made from one half of the brick was crushed at once, while the cube from the other half was saturated with water, then frozen and thawed twenty times, after which it was dried and crushed. All the cubes were crushed between parallel steel faces, in the position they would be laid in the wall. Thick paper was placed between the brick and steel plates to remove any irregularities on the surface of the brick. The argument that paper used in this way acted as wedges entering the slight depressions and there splitting the cubes, did not appear to be true.

Since natural weathering action on a brick wall proceeds from the outside of the brick, the four surfaces of the cubes for artificial weathering were not cut nor polished smooth.

Before selecting the sample cubes, cubes were cut from various portions of a brick and tested to determine whether they would show uniform strength. The results of these tests on several brick showed that cubes taken from the center of the brick were *one-third stronger* than those from the ends, but pairs of cubes taken from the ends of the brick checked closely as shown below:

End.	Middle.	End	Middle.
33,200	41,500	14,000	18,000
31,000	43,000	13,800	18,300

During the freezing and thawing tests, repeated twenty times, only two of the building brick showed any sign of injury, and these revealed no cracks but had the edges slightly rounded. Two samples of paving brick which showed high absorption were tested in the same way and their strength and appearance were but little altered. The effect of freezing may be imitated by

the crystallization of a strong solution of a salt, like sodium sulphate, in which the cube is immersed, but it is doubtful how accurate such results may be, so that in the present work actual freezing tests were applied.

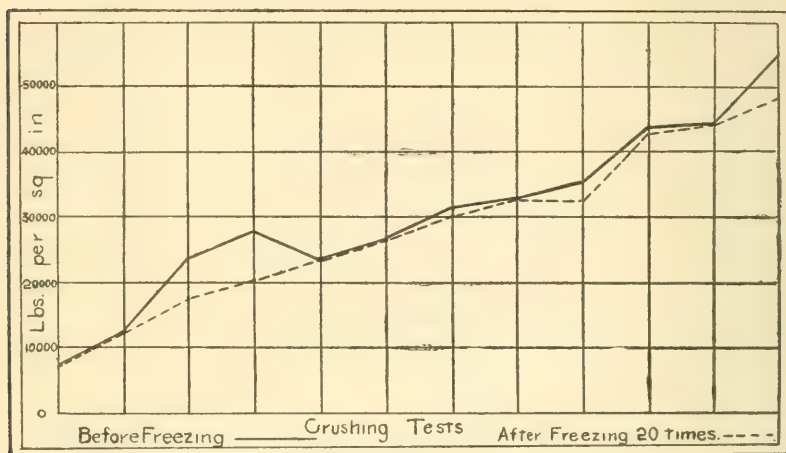


Fig. 23—Freezing tests on West Virginia building brick.

Figure 23 shows that it is not always the strongest brick according to the crushing test that resists the action of the weather best. The crushing strength of common building brick is usually stated as ranging from 1,000 to 6,000 pounds per square inch. The West Virginia building brick according to our tests range from 1,700 to 6,500 pounds per square inch; the paving brick tested gave a range of 4,800 to 15,000 pounds; the fire brick varied from 370 to 1,175 pounds.

Absorption Test.—The absorption test is usually included in specifications, though it is now regarded by many engineers as of doubtful value. Absorption is defined as the weight of water absorbed by a brick stated in per cent. of the weight of the dry brick. The results of this test do not usually conform to those of the rattler tests nor to the various tests of building brick.

The N. B. M. A. now recommend that paving brick be burned to the point in vitrification that gives the best rattler test without regard to the absorption. Some city specifications still insist on a very low absorption, forcing brick manufacturers to work to this end rather than making brick strong by the rattler

test. Some of these city specifications should be altered in this respect to secure the best materials.

The absorption test as applied to building brick is even more indefinite, the size of the pores being more important than the amount of porosity. It is claimed that while large pores allow the free entrance of water, they also permit an easier exit, so that in cold weather the water moves freely without breaking the brick.

In applying the absorption test the dried broken brick are weighed, then placed in water for a given length of time, and reweighed. Since absorption is not complete until several months of exposure to the water, the method proposed by the Wisconsin Geological Survey¹ has been used in the present work. The brick had the air removed as far as possible, then warm water was added from the bottom; and the process was repeated to make certain the brick was saturated. It was found that with a single treatment in this method the absorption was more complete than after two weeks of ordinary treatment with water.

Common brick range from 10 to 20 per cent., while specifications when made usually require less than 15 per cent. Paving brick range around 3 per cent. The West Virginia building brick tested gave from 4.1 to 16.5 per cent. absorption; the paving brick ranged from 1.8 to 5.9 per cent.

TESTS ON WEST VIRGINIA BRICK.

The material for these tests has been kindly furnished the Survey by the various companies. We had hoped to be able to make a complete series of tests of brick from all the leading companies, but unfortunately for the success of this endeavor, a number of companies refused to accept the invitation for free tests of their products and the series is therefore incomplete. It is hoped that the results of this investigation will prove of interest and value to the companies who have aided in this work and thus repay them in part for the trouble they have taken.

The brick tested are given by number and not by name, so that these results may not be used to the injury of any company whose brick, even though of high quality, may show lower tests than those of another company. In order to make the work of direct value to the manufacturers and to compensate them in part for their assistance, the Survey has sent to each company the re-

1. Wisconsin Geol. Survey IV., p. 65.

sults of tests on their own product with suggestions and explanations of the significance of the tests. Brick from the following companies have been tested by the Survey :

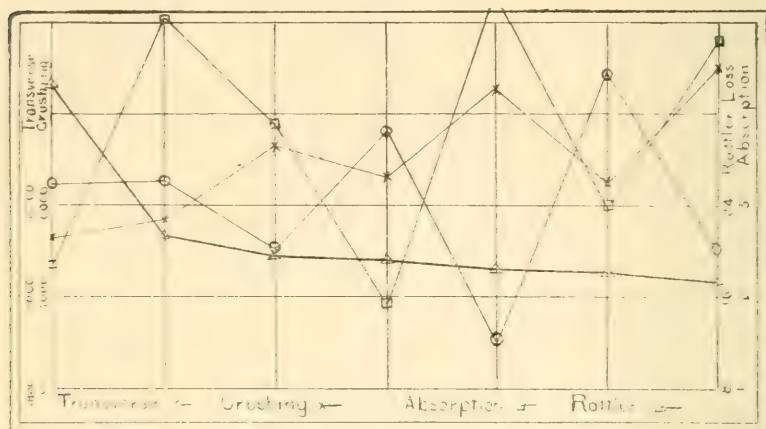


Fig. 24—Tests of paving brick plotted in order of decreasing rattler tests to show lack of agreement with other tests.

Thornton Fire Brick Co.....	Grafton
West Virginia Paving & Pressed Brick Co.....	Huntington
Huntington Red Brick Co.....	Huntington
Hammond Fire Brick Co.....	Hammond
Colfax Brick Co.....	Colfax
Camden Clay Co.....	Spilman
Suburban Brick Co.....	Moundsville
Kanawha Brick Co.....	Charleston
Morgantown Brick Co.....	Morgantown
Elkins Brick Co.....	Elkins
Magnolia Brick Co.....	New Martinsville
Piedmont Fire Brick Co.....	Piedmont
Parkersburg Brick Co.....	Parkersburg
Mack Manufacturing Co.....	New Cumberland

The results of the tests on paving brick are given in the following table, and illustrated by the curves in figures 20 and 24.

PAVING BRICK.

No.	Size.	Rattler test (in duplicate)				No. Broken.	Absorp- tion per cent.	Crush- ing lbs. sq in.	Trans- verse
		No. used.	Loss' 600.	Loss' 1200.	Loss' 1800.				
1—	9x4x3	18	9.4	14.3	16.87	1	4.9	8,000	2,082
2—	8½x4x2½ ..	22	9.5	14.1	17.64	0	2.8	5,716	2,575
3—	8x4x2¼	24	11.2	14.9	19.09	7	5.7	14,250	1,870
4—	8½x4x2½ ...	24	13.4	18.0	19.77	1	1.8	5,135	2,372
5—	9x4x3⅔	18	9.0	16.1	20.17	0	3.8	7,503	2,088
6—	8½x4x2½ ...	24	10.3	15.9	20.88	1	5.1	4,765	2,211
7—	9x4x3	18	12.5	25.1	34.16	3	2.5	4,763	2,249
8—	9x4x3⅔	18			12.92	0			
9—	9x4x3⅔	18			20.73	6			
10—					24.25				

In the above table, Nos. 8 and 9 were made by Prof. Edward Orton, Jr., on samples of brick from West Virginia. No. 10 represents the average of six good grades of brick tested by the Iowa Geological Survey. All of these tests were made according to the N. B. M. A. specifications.

The following table gives the results of tests on West Virginia building brick and fire brick, which may be shown by curves as in figures 22, 25, 26 and 27.

BUILDING BRICK.

—POUNDS PER SQUARE INCH.—

No.	Size.	Crushing.	Crushing after Freezing.	Transverse.	Absorption. per cent.
1—	8½x4x2½	1728	1704	436	15.5
2—	8x4x2¼	1646	1675	518	16.5
3—	8½x4x2½	3362	3363	1273	9.5
4—	3½x4½x2 2-5..	4902	4332	1293	8.4
5—	8x4x2½	4334	3175	1335	8.4
6—	8½x4¼x2½ ..	5531	5520	1384	10.7
7—	8x3¾x2½	3568	3560	1492	4.4
8—	8x4x2½	6154	5821	1705	8.5
9—	8½x4x2½	3846	2624	1718	8.7
10—	8x4x2½	7782	7613	1920	4.6
11—	8x4x2½	6522	5935	1870	5.7
12—	8¼x4x2½	7977	7896	2210	5.1

FIRE BRICK.

1—	9x4¼x2½	1174	293
2—	.....	635	268
3—	.....	370	193

A study of these tables of tests on paving and building brick shows the high quality of the West Virginia product, and the results compare very favorably with those of tests made in other states and published in the various state reports. In the work

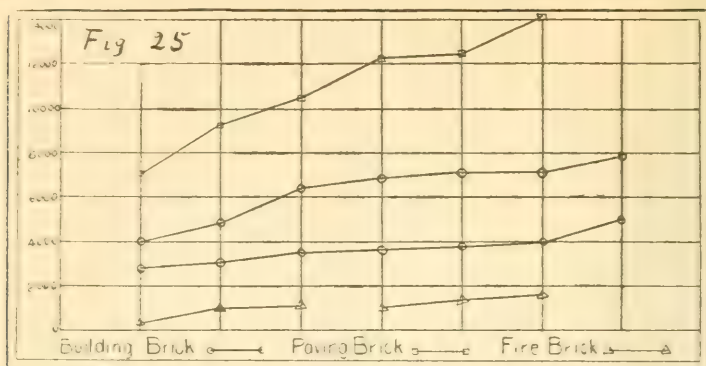


Fig. 25—Crushing Tests on five samples of West Virginia brick.

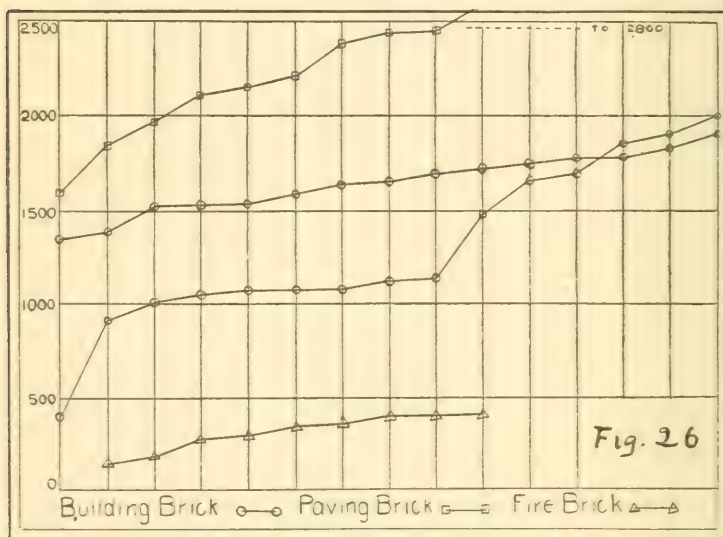


Fig. 26—Transverse Tests on four samples of West Virginia brick.

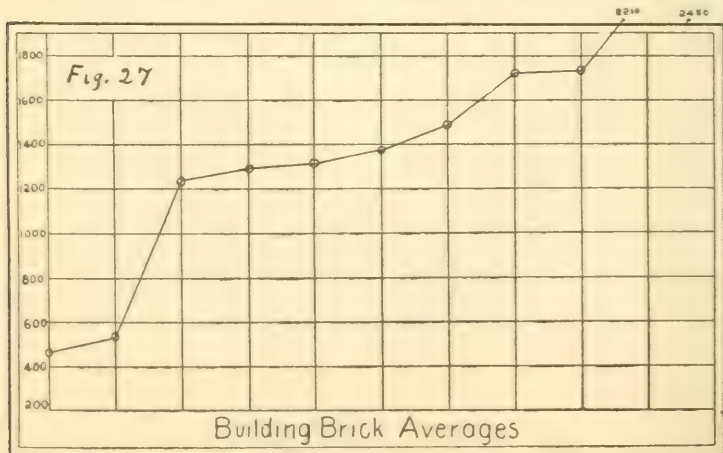


Fig. 27—Average Transverse Tests on samples from eleven manufacturers of building brick.

for this chapter there were made by Mr. Grout eight duplicate rattler tests, 425 transverse tests, 150 crushing tests.

A series of tests was also made on brick taken from various parts of the kiln to determine the strength of properly burned brick as compared with over and under-burned product. Some very interesting results were obtained from such comparisons by Professor Marvin at the University of Kansas.¹ The officers of the Morgantown Brick Company extended to the survey the favor of using the product from one of their down-draft kilns. The color of the brick in different parts of the kiln is usually a sufficient guide for sorting the brick by the manufacturer and he has no trouble in selecting soft under-burned brick or hard and brittle over-burned product, but tests show there is considerable difference among the soft brick and among the thoroughly burned brick in different parts of the kiln, showing that the draught in the various parts of the kiln is far more variable than has been usually inferred.

In this series of tests it was found that the brick of lowest strength were in the bottom courses near the side of the down-draft kiln. The brick near the center of the bottom courses were of low strength, but were stronger than those near the side. The brick from the center of the top courses were only of fair degree of strength, while the best brick came from the center of the kiln and in a few courses below.

The time was not sufficient to study the product from kilns with different arrangements of flues and fire boxes, but such a study from a variety of kilns made in connection with a study of the system of draught used, might throw important light on the best arrangement of kilns, which would give economy of fuel and larger proportion of salable product.

In some brick plants in the State the under-burned brick are sorted out and when a sufficient quantity has accumulated to fill a kiln they are burned a second time to bring them to the required temperature for serviceable brick. These twice burned brick are sold with good single burned brick and it is almost impossible to detect by the eye any difference between them, except when fine cracks have been formed over the surface. When they are known to be doubly burned some contractors will refuse

1. Kan. Acad. of Science, Vol. 19, p. 96; 1905.

to buy them on the supposition that the strength of the brick is greatly lowered.

A series of under burned salmon colored brick were burned in a kiln with a series of brick burned for the first time, and the two tested with the following results :

	Transverse Test.	Crushing Test on 2½-inch cubes.
Once burned.....	5,518	12,000
Twice burned.....	4,286	7,180
Salmon brick.....	3,000	

These tests showed a marked decrease in strength in the twice burned brick, although their strength was high enough to be used safely in any form of construction. The twice burned brick was stronger than the once burned salmon colored or under burned brick.

CHAPTER XI.

SAND-LIME BRICK.

A new feature in the brick industry of this country which has been prominent for some years in Germany, is the manufacture of sand-lime brick. In several states the industry is attracting much attention and a number of plants have been installed. The industry is especially adapted to sections where good deposits of sand are found and where suitable clays for high grade brick are absent or where the cost of fuel is high.

The progress of the industry has been hindered by the usual prejudice against a new and untried building material, a fear that it might not withstand the destructive elements of weather and time. As the durability of these brick is being proved the adverse criticism is gradually being removed, and the American industry is growing at a rapid rate.

The sand-lime brick manufactured at the present time is not an experiment, but a demonstrated fact and must be included in any classification of building materials. In this industry, as in the clay manufacture, low grade and unsatisfactory products will reach the market through the use of poor materials or careless manipulation. Such mistakes have a greater retarding influence in new industries than in old established processes.

When poor clay brick enter the market, the consumer instead of condemning the use of brick, looks to another company for better brick. But when the new product from a sand-lime brick plant proves of inferior quality, the consumer is very apt to condemn the whole process and use another kind of material. Thus arises the conflicting testimony on the value of sand-lime brick. In one section it is regarded as a visionary, theoretical project, while in another the plants are increasing their capacity to supply a growing demand.

In West Virginia at the present time there is not a single sand-lime brick plant, though they are established on all sides of

us, at Pittsburg, Cumberland, and in Virginia, Kentucky, Ohio. The State possesses the materials in abundance and these have been tested from a number of localities, resulting in a good product.

With the cheap and abundant fuel, the large and desirable clay deposits, the State has not looked to this new industry as a practical investment. It might, however, be advantageously combined with the sandstone quarry industry in some sections and so use the refuse rock of the quarry with profit. Where conditions of manufacture are favorable to low cost and high class product it might prove a winning competitor with fine pressed brick for ornamental construction.

The purpose of this chapter is to give the people of this State information about this new industry, the process of manufacture, and materials used. No original work is given and the chapter is a compilation of results of the experience and investigation of workers in other states. The article is based especially on the work of S. V. Peppel of the Ohio Geological Survey, who has made the most complete study of this subject yet written in America, and the writer wishes to give him due credit for the data used, which are freely taken from two articles by Mr. Peppel listed below.¹

HISTORY.

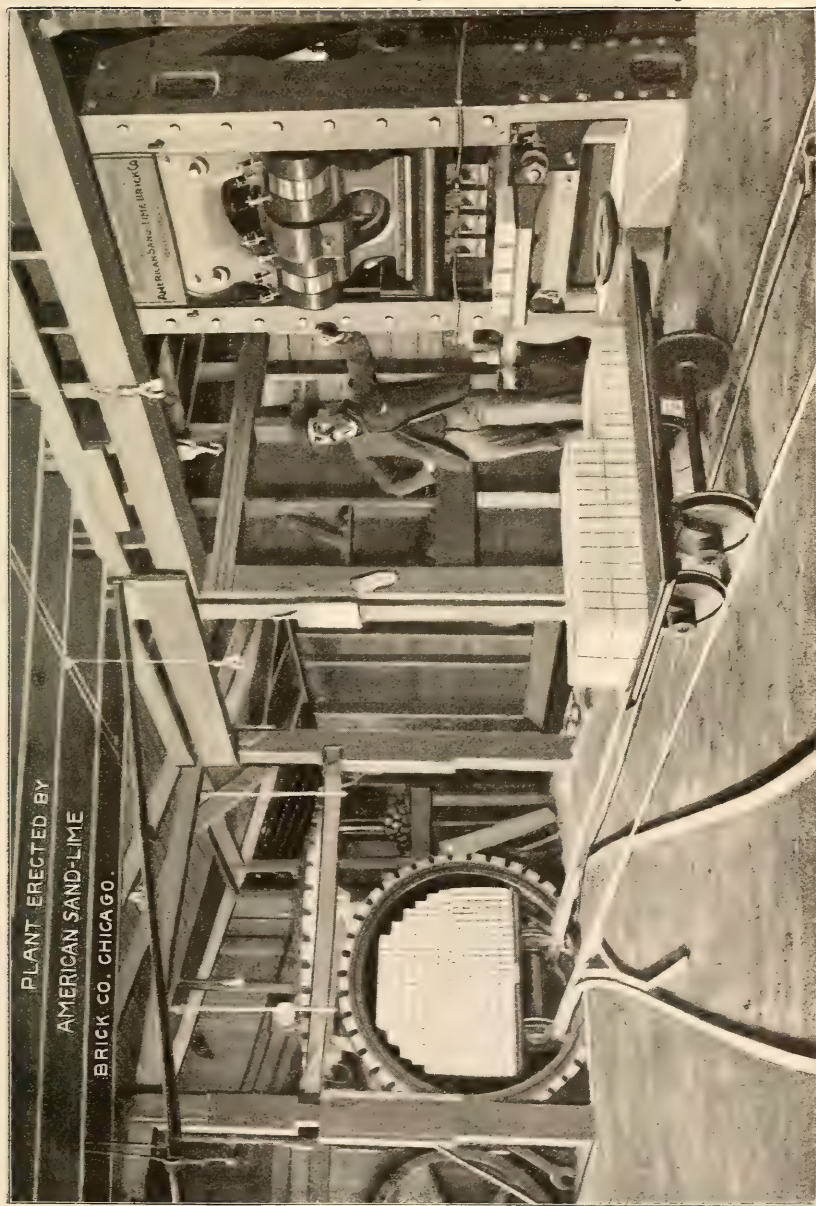
Brick made from sand with an addition of lime carbonate have been made in Germany for fifty years or more. About 30 per cent. of lime is added and the brick hardened by exposure to the air for several months, or by hardening in air rich in carbon dioxide. These brick are designated as mortar brick.

In 1880 Dr. Michaelis patented a process in Germany for hardening a mixture of sand and lime by steam under pressure. This patent was allowed to lapse so that the present patents are on details of manufacture and machinery. The industry has made remarkable progress in the last ten years in Germany, where there are 200 plants with an annual output of nearly 400,000,000 brick.

The first sand-lime brick plant in the United States was built at Michigan City, Indiana, in 1901, by the Ohlemacher Brick Com-

1. On the manufacture of sand-lime brick in *Trans. Amer. Ceramic Soc.* Vol. V., p. 168; 1903.

The Sand-Lime Brick Industry, U. S. Geol. Survey, *Mineral Resources for 1903*, p. 866.



PLANT ERECTED BY
AMERICAN SAND-LIME
BRICK CO. CHICAGO.

Plate XX.—Interior View of an American Sand-Lime Brick Plant,
Showing the Hardening Cylinder and Brick Press.

pany, operating under the Kleber patent. In 1902 a plant was erected at Wilmington, North Carolina, by the Hydraulic White Brick Company, operating under the Huennekes patent.

According to the U. S. Geological Survey statistics there were in 1901 five factories in this country, with a total capacity of 100,000 a day; in 1902 twenty plants which sold 6,000,000 brick that year; in 1903, about fifty plants which sold about 20,000,000 brick.

CHEMICAL REACTION.

When silica and lime carbonate are brought together under conditions of increased temperature and pressure, a chemical reaction takes place whereby the silica acts on the carbonate of lime, replacing the carbonic dioxide with silica forming a lime silicate. If magnesia is present there will be formed a lime-magnesia silicate, or in the presence of steam hydro-silicates of these bases.

These silicates form a bond which holds the sand particles together. The process is one of cementation, while in clay brick the particles are held together by fusion of certain particles in the clay. The strength of the sand-lime brick is found to depend to some extent on the nature of the silicate formed, lime silicate, according to tests being somewhat stronger than lime-magnesia silicate; and to a greater extent on the amount of silicate formed.

The chemical composition of the German sand-lime brick is given as:¹

Silica	84	per cent.
Iron and alumina oxides.....	2	" "
Lime oxide.....	7	" "
Magnesia oxide, water, carbondioxide, alkalies.....	7	" "
	100	" "

RAW MATERIALS.

Sand.

The brick may be made from almost any grade of sand, but the purer the quality of sand the better the resulting product. Poor grades of sand may make brick of apparently good quality when taken from the cylinders, but on exposure to the weather will crack and disintegrate in course of time.

1. U. S. Geol. Survey, Min. Resources, 1903, p. 871.

The main impurities in sand are clay or loam, mica, feldspar, and iron oxide. The clay impurity up to 8 per cent. does not seem to injure the strength of product. High percentages of clay lower the weather resisting properties of the brick and give higher water absorption, thus injuring the quality. The influence of clay on the strength of the brick is shown by the following experiments of Peppel,¹ when the molding pressure was 10,000 pounds per square inch, the steam pressure 150 pounds per square inch, temperature in hardening cylinder 185° C. and time of exposure to steam, ten hours.

Composition of mixtures.				WHEN TESTED.							Per cent. water ab- sorption.
Parts coarse sand.	Parts fine sand.	Per cent. of Kaolin.	Per cent. dolomitic lime.	At once after hardening.		After ageing.		After freez- ing.			
				Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.		
4	1	2.5	5	2766	338	2449	194	2917	219	8.32	
4	1	5.0	5	2500	210	2376	277	2481	181	8.00	
4	1	10.0	5	1943	184	1687	157	1910	121	8.50	
4	1	20.0	5	1705	162	1325	138	1477	93	9.00	

The mica and feldspar are usually present in but small amount and do not appear to be injurious up to 10 per cent. The strength of the brick is somewhat lowered by the presence of 10 per cent of feldspar, and if kept at high temperature for ten hours may alter and form soluble salts, thus forming a white wash on the surface.

Peppel concludes from his experiments that by use of steam at a pressure of 120 pounds and using shorter time in cylinder, any danger of feldspar component will be practically eliminated. Mica, as far as it has been examined, appears to be unchanged in the brick.

Texture of Sand.—Most of the sand should pass a screen of 20 meshes to the inch or with a good gradation in size from coarse to fine should pass a 40-mesh screen. Fine sand with the coarse seems to be essential to good results. Dr. Michaelis regarded two-thirds coarse sand to one-third of fine as making the

1. Transact. Amer. Ceramic Soc. Vol. V., p. 174.

best mixture, and this was the conclusion of Peppel from a series of experiments, who explains the action as follows,¹ "The fine sand not only fills the spaces between the coarser particles, but assists in the even distribution of the lime, and very much accelerates the chemical reaction so necessary to strength."

Sand with sharp corners is regarded as better than that with rounded corners, as it is more readily acted upon chemically, and forms a firmer bond, giving higher crushing and tensile strength. If the sand from the bank is too wet it is dried in a sand drier before use.

CHEMICAL COMPOSITION OF SOME WEST VIRGINIA SANDS.

In many sections of the State there are extensive sand deposits which might be available for this brick. The composition of a few sandstones will be given to show the low percentage of clay in them.

	Junior, Barbour Co.	Charleston, Kanawha Co.	Parkersburg, Wood Co.
Silica	97.29	90.41	89.73
Alumina	1.29	4.47	4.67
Iron	0.39	1.24	1.93
Lime	0.04	trace	0.12
Magnesia	0.07	0.29	0.43
Alkalies	0.29	1.14	1.58
Loss on ignition, etc.....	0.63	2.45	1.54

Lime is produced in large quantities in the northeastern part of the State from limestone with following composition:

Lime carbonate.....	95.55	98.21
Magnesium carbonate.....	2.44	0.86
Silica	0.12	0.02
Iron and alumina.....	1.01	0.75

Limestone is also found in this section which would make a magnesian lime, the rock containing 54.72 per cent. lime carbonate and 29.18 per cent. magnesium carbonate.

Lime.

Both pure and magnesium limes are used. Tests made with the two kinds of lime showed a stronger brick and lower absorption when pure limes were used. The pure lime is made from a limestone carrying 85 to 100 per cent. of lime carbonate, and the

1. Transact, Amer. Ceramic Soc. Vol. V., p. 172.

magnesian limes from stone with 56 to 60 per cent. of lime carbonate and 40 to 45 per cent. of magnesium carbonate.

The pure limes make a stronger brick than the magnesian or dolomite limes as shown by the following tests.¹

PARTS.				AT ONCE AFTER HARDENING.		AFTER FREEZING.		Water absorption.
Coarse sand.	Fine sand.	Pure lime.	Dolomitic lime.	Crushing strength.	Tensile strength.	Crushing strength.	Tensile strength.	
2	1	10		7745	437	9007	371	8.62
2	1		10	5187	286	5853	314	9.11

The lime must be slaked for this work. In some processes the lump lime is ground and added to the moist sand, resulting in a partial hydration of the lime, which is completed in pug mill or other mixers where the necessary amount of water is added.

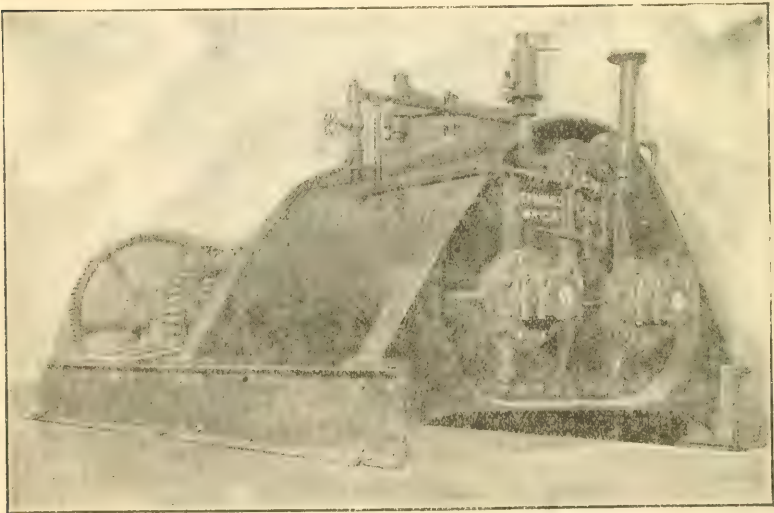


Fig. 28—Reliance mixing machine for sand-lime brick.

1. Furnished by Schwarz System Brick Co., New York.

In other methods the lime is slaked before mixing with the sand. This is accomplished by placing the lime in boxes with an excess of water. The resulting putty is dried and ground. Another method, which is coming into use, slakes the lime to a fine dry powder known as lime flour. Enough water is added to slake the lime with a slight excess which is evaporated by the heat generated in the process. The water is added in small quantity and the lime subjected to action of steam in enclosed cylinders.

The preliminary slaking insures a uniform lime product and complete hydration which is more important when the slow slaking magnesian limes are used than in rapid slaking pure limes. Lime which is air slaked should not be used. The quantity of lime used varies from 5 to 10 per cent. High percentages are found to give greater strength to the brick, but the lower percentages give sufficient strength and the additional cost of lime would not be compensated by the increase in strength.

PROCESS OF MANUFACTURE.

The lime and sand are fed through measuring machines into the mixers where they are thoroughly mixed. Mixing machines fall under four types, wet pan, pug mill, ball or tube mill, inclosed cylinders with curved paddles. The kind of machine will depend on whether the lime is slaked or not before mixing, and the personal judgment of the operator as all these methods have been successfully used. The Reliance mixing machine of the Schwarz system is shown in figure 28.

From the mixer the sand-lime material is carried by elevators to storage bins and left for 12 to 18 hours, or is taken directly to the press, some companies advocating the former method and others preferring the latter.

The presses used for sand-lime brick are of German and American manufacture. The former has a rotary table and the brick are delivered at the top of the die so they are picked off and not pushed to one side. As the brick are very tender at this stage the edges are apt to be roughened or corners broken in sliding over the delivery table.

In the Kahl press the rotary table passes the empty mold under a measuring box, where it is filled and passes around to the plunger where the pressure is applied from below. A further rotation brings the brick up to the table where it is picked off. The

capacity of the machine in different sizes is 12,000 to 13,000 in ten hours. In the Komnich press used by the American Sandstone Brick Company, the rotary table and measuring box are similar to preceding type but the pressure comes from above, and two brick are molded at one time.

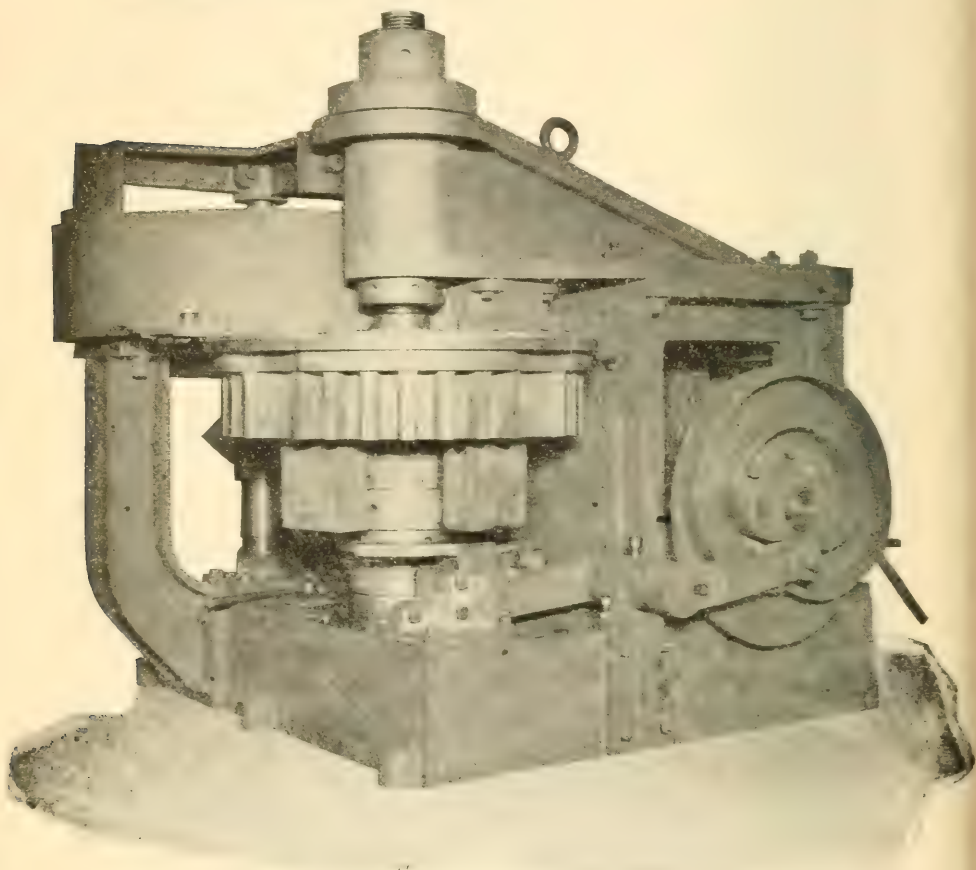


Fig. 29.—Columbia Press for Sand-Lime Brick.

The Schwarz system Brick Company press, known as the Columbia, makes one brick at a time, receiving the full power of the press. The bricks are elevated to the table from which they are lifted, avoiding to a large extent the danger of breaking the edges. The press is operated by an eight and one-half horse

power engine placed on the same bed plate with the press, and is illustrated in figure 29.

The American Sand-Lime Brick Company machines are dry press brick machines as described in the section on clay machinery in this volume. These machines are claimed to be stronger, more durable, and of greater capacity than the German machines, but are liable to injure the edges of the brick as they are pushed forward across the delivery table.

The requirements of a good brick press for this industry are given by Peppel as follows:¹

1. The press must be able to regularly deliver a pressure of from 200 to 250 tons per brick, and yet not break down if by accident the pressure rises somewhat higher.

2. The filling of the mold must be accomplished with great accuracy and uniformity.

3. All the working parts must be so arranged that they will be free from contact with loose sand; otherwise, they will cut out at an alarming rate.

4. The dies and mold linings must be made of the hardest material obtainable.

The best results seem to be obtained with a pressure of 15,000 pounds to the square inch. The bricks from the press while ten-

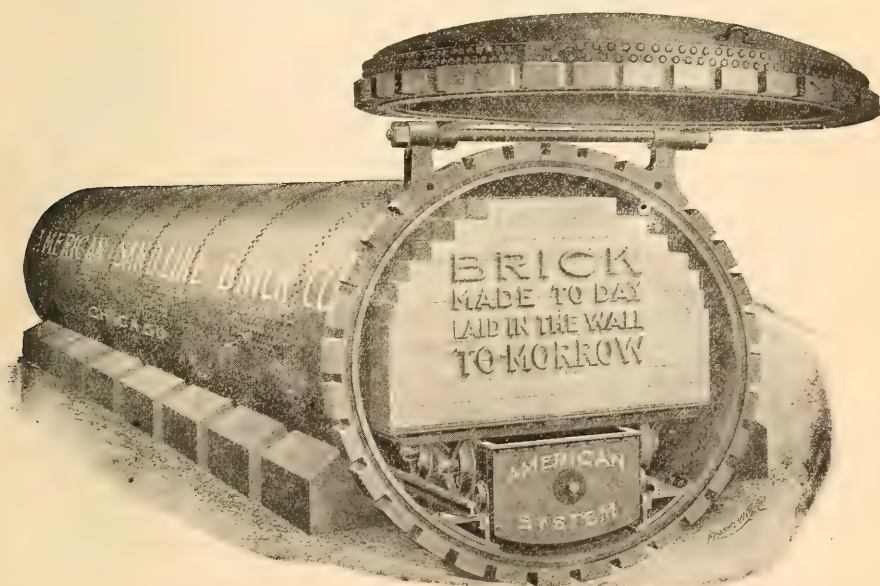


Fig. 30—American hardening cylinder for sand-lime brick.

1. Trans. Amer. Ceramic Soc. Vol. V., p. 201.

der are yet hard enough to be stacked on top of each other upon steel cars which are then pushed into the hardening cylinder.

This cylinder is made of $\frac{5}{8}$ to $\frac{3}{4}$ inch boiler iron, six or seven feet in diameter and 30 to 60 feet long, with one head removable by aid of a crane and fastened with bolts. The fastenings must be firm to withstand the pressure and avoid accidents. Steam is introduced usually under a pressure of 150 pounds for ten hours. Peppel's experiments¹ seem to show that with this pressure of steam four hours time is sufficient, and six to eight hours with a steam pressure of 120 pounds, or eight to twelve hours with 100 pounds steam pressure. If much feldspar was present the longer time exposure might alter this mineral and furnish material for efflorescence or white wash. He concludes from his experiments that the brick for best results should be kept for eight to ten hours with a steam pressure of 120 pounds. The cylinder constructed by the American Sand-Lime Brick Co. is shown in figure 30. Plate XX shows a view of one of the plants equipped with this company's machinery.

PHYSICAL PROPERTIES OF SAND-LIME BRICK.

Absorption.—About one and a half per cent. of water are retained in normal air dried sand-lime brick. The water absorption is nearly complete in 24 hours, and after 48 hours ranges from 8 to 10 per cent., or about the same as in clay brick.

Crushing Strength.—The crushing strength ranges from 2,500 to 7,745 pounds. The average crushing strength of natural sandstone is about 6,535 pounds.² Dry pressed clay brick crush at 5,000 to 6,700 pounds.

Freezing Tests.—Severe freezing tests in the laboratory fail to show any evidence of weakness. Buildings erected in this country with sand-lime brick fail to show any deterioration, and this is also true in Germany after eight to ten years of exposure.

Prof. Ira Woolson, of Columbia University, has made an extended series of freezing tests on sand-lime brick. The brick were saturated with water, then rapidly frozen by artificial freezing methods. The frozen brick were then plunged into warm water and thawed, then frozen again. The operation was re-

1. Trans. Amer. Ceramic Soc. Vol. V., p. 191.

2. U. S. Geol. Survey Min. Resources, 1903, p. 869.

peated many times and the brick tested for crushing strength and the results compared with brick made at the same time and out of same material which were not frozen. "In every case except when the brick contained considerable quantities of clay, there was no falling off in the crushing strength. From the foregoing it is evident, that if properly manufactured, sand-lime brick is not at all susceptible to the ravages of frost and moisture."

Fire Tests.—A large number of severe fire tests on these brick was made by Mr. Peppel, who sums up his results as follows:¹

"The application of great heat, followed by sudden quenching with water, destroys to some extent the bond on the surface and to a little depth beneath, but leaves the brick safe and intact. There was seldom any breaking or cracking of the brick, and the softening did not seem to penetrate the brick to any extent. This is perfectly natural, since the brick are largely made of quartz which is a poor conductor of heat."

Color.—The natural color of sand-lime brick is light gray, though it varies with the sand. Any desired tint can be secured by addition of mineral pigments at comparatively small cost.

COST OF PLANT AND PRODUCTION.²

A well equipped sand-lime brick plant with a capacity of 20,000 brick in ten hours, independent of site, would cost somewhere near \$25,000. The cost of production, independent of interest on the investment, would be under average conditions about \$4.00 per 1,000 brick. The selling price ranges from \$8.00 to \$15.00 a thousand.

SYSTEMS OF MANUFACTURE.

Five systems have been especially promoted in this country. The American Sandstone Brick Machinery Company, of Saginaw, Michigan, using the Komnich system. The Ohlemacher Brick Company, of Michigan City, Indiana, using the Kleber system. The H. Huennekes & Co., of New York City, operating under their own patents. The Schwarz System Brick Company, of New York, using their own patents. The American Sand-Lime Brick Company, of Chicago.

1. U. S. Geol. Survey Min. Resources, 1903, p. 870.

2. Trans. Amer. Ceramic Soc. Vol. V., p. 217.

PRESENT CONDITION OF THE INDUSTRY.¹

In 1903 there were 16 plants in the United States engaged in the manufacture of sand-lime brick. The number of brick sold was 20,860,000, valued at \$155,400, or \$7.45 per thousand.

In 1904 there were 57 plants with a total value of product of \$463,128. These plants made 50,646,000 common brick with an average value of \$6.44 per thousand, 14,471,000 front brick with a value of \$9.42 per thousand, and 20,000 fancy brick with a value of \$26.10 per thousand, or a total of 65,137,000 sand-lime brick.

These 57 plants according to the government report are located in the following states and territories:

Alabama	3	Louisiana	1	Pennsylvania ...	4
Arizona	1	Kentucky	1	South Carolina..	2
Arkansas	2	Maryland	1	South Dakota....	1
California	4	Michigan	10	Tennessee	1
Delaware	1	Mississippi	1	Texas	1
Florida	2	New Jersey.....	1	Virginia	2
Indiana	4	New York.....	5	Washington	1
Iowa	2	North Carolina..	1	Wisconsin	1
Kansas	1	Ohio	3		57

Michigan holds first rank in sand-lime brick output, Indiana second and New York third.

1. From U. S. G. S. Mineral Resources for 1904 on Clay Industries, by Jefferson Middleton.

CHAPTER XII.

A STUDY OF STATISTICS.¹

There is a more or less widespread opinion in this State that the clay industry holds no comparison to the coal, oil, or gas industries in the value of output, which is true at the present time in West Virginia, where the value of clay production is about one-sixteenth that of coal in which the State holds second rank among the states of the Union. Its clay industry is about one-tenth that of oil, and one-third that of natural gas, in both products the State holds second rank.

The study of the developed resources of this State would thus indicate that the clay industry was almost insignificant and not worthy of study and advertisement by one of the departments of the State. A study of conditions in other states does not support this view, but illustrates the great importance of a careful exploitation of this branch of the State's resources.

In Ohio, which holds fourth rank in coal output, the value of the clay industry is not far behind that of coal. Ohio holds first rank in oil and the clay industry lacks one million dollars of reaching the same value. It ranks fourth in natural gas and the clay industry has a value six times as great.

Pennsylvania holds third rank in oil, first in natural gas, and the clay industry has a greater value of production than either the oil or gas.

The value of clay products in Ohio is ten times that of West Virginia, in Pennsylvania it is seven times that of this State. West Virginia ranks tenth in value of clay products with a value in 1903 of \$2,558,560, of which one-half represents the white ware pottery output and building and paving brick make up most of the remainder.

1. Statistics in this chapter are taken from reports of U. S. Geol. Survey.

The reason for the marked contrast in clay industries in Pennsylvania and Ohio with West Virginia cannot be explained by the absence of good clay deposits in this State, nor by lack of cheap and excellent transportation facilities, nor by remoteness from market, as has been shown time and again in the preceding pages of this report. It is due to lack of development, depending in many cases on lack of appreciation of the value of these deposits, and also on lack of knowledge of the location, size and value of the deposits. It is the purpose of this report to present to the public these data as far as we have been able to collect them, and it is hoped that as a result the clay industries will be developed in better proportion to the other well established mineral industries of the State.

West Virginia has good deposits of fire clay and the industry amounted to less than \$75,000 in 1903, and only \$46,296 in 1904, while in Ohio it yields \$1,500,000, and in Pennsylvania \$6,500,000.

With the good deposits of stoneware pottery clays, this industry has a value of about \$19,000, while in Ohio it runs over \$1,000,000, and \$500,000 in Pennsylvania.

Ornamental pressed brick industry in West Virginia amounts to about \$5,000 a year. In Ohio it is over \$600,000, and in Pennsylvania over \$1,000,000.

The clay industry reached a lower value in this State in 1904 than in 1903 or 1902, and this was true in the industry of the United States, due in part to labor troubles in the various building trades.

The following tables give the rank of the State in clay industry from 1894 to the present, the prices of brick, the total value of the clay products, the value of branches of the industry, value of clay products in the United States, and the statistics of the clay industry in this country for 1904 as given by the United States Geological Survey:

RANK OF WEST VIRGINIA IN CLAY PRODUCTS BY YEARS.

1904	1903	1902	1901	1900	1899	1898	1897	1896	1895	1894
11	10	9	9	9	13	13	13	16	16	21

PRICES OF BRICK (PER 1,000) IN WEST VIRGINIA BY YEARS.

Year.	Building.	Paving.
1904.....	\$6.89	\$11.87
1903.....	6.55	11.13
1902.....	6.50	9.56
1901.....	5.81	8.84
1900.....	6.83	8.88
1899.....	5.40	7.77
1898.....	5.52	8.69
1897.....	5.37	7.57
1896.....	5.59	8.28
1895.....	5.82	7.21
1894.....	5.86	7.94

TOTAL VALUE OF WEST VIRGINIA CLAY PRODUCTS BY YEARS.

1904	\$2,074,549
1903	2,558,560
1902	2,518,544
1901	1,946,480
1900	2,016,765
1899	1,451,539
1898	1,027,525
1897	1,115,254
1896	902,944
1895	895,777
1894	673,006

THE CLAY INDUSTRIES OF WEST VIRGINIA BY YEARS.

Product.	1904.	1903.	1902.	1901.	1900.
Brick, Common.					
Quantity ..	68,133,000	88,060,000	81,166,000	60,004,000	103,760,000
Value	\$469,501	\$576,404	\$527,661	\$348,452	\$708,861
Pressed.					
Quantity ..	388,000	269,000			1,610,000
Value	\$5,380	\$3,356			\$16,797
Vitrified.					
Quantity ..	39,620,000	51,762,000	60,549,000	62,805,000	53,492,000
Value	\$470,339	\$576,000	\$578,777	\$555,389	\$474,880
Fire	\$11,814	\$70,802	\$23,633	\$102,300	\$149,257
Drain Tile...	\$1,398	\$1,499	\$1,226	\$1,485	\$1,346
Pottery.					
Earthenware.	\$18,923	\$16,600	\$15,018	\$13,069	\$9,827
White ware..	\$876,282	\$1,099,900	\$1,026,446	\$419,873	.....
Sewer pipe..	None.	None.	None.	None.	None.

THE CLAY INDUSTRIES OF WEST VIRGINIA BY YEARS, CONTINUED.

Product.	1899.	1898.	1897.
Brick, Common.			
Quantity	49,903,000	28,516,000	30,594,000
Value	\$269,656	\$157,425	\$164,177
Pressed.			
Quantity	2,196,000	1,690,000	2,033,000
Value	\$16,218	\$12,690	\$19,246
Vitrified.			
Quantity	53,451,000	33,416,000	38,271,000
Value	\$415,000	\$290,266	\$289,886
Fire	\$54,400	\$5,155	\$28,696
Drain Tile.....	\$3.656	\$1,310	\$400
Pottery.			
Earthenware		\$518,218	\$169,520
White ware.....			\$350,000
Sewer pipe.....			\$81,629
Product.	1896.	1895.	1894.
Brick, Common.			
Quantity	29,462,000	35,815,000	38,719,000
Value	\$164,831	\$208,337	\$227,032
Pressed.			
Quantity	972,000	1,845,000	.....
Value	\$11,370	\$18,400	.....
Vitrified.			
Quantity	21,485,000	62,330,000	8,059,000
Value	\$177,856	\$449,388	\$63,964
Fire	\$1,500	\$4,000	\$500
Drain tile.....	.....	\$140	\$360
Pottery.			
Earthenware	\$130,000	.....	.....
White ware.....	\$280,707	.....	.....
Sewer pipe.....	\$77,171	\$196,000	\$350,000

VALUE OF CLAY PRODUCTS IN THE UNITED STATES BY YEARS.

Year.	Brick and Tile, etc.	Pottery.	Total.
1904	\$105,864,978	\$25,158,270	\$131,023,248
1903	105,626,369	25,436,052	131,062,421
1902	98,042,078	24,127,453	122,169,531
1901	87,747,727	22,463,860	110,211,587
1900	76,413,775	19,798,570	96,212,345
1899	79,547,120	17,250,250	95,797,370
1898	59,898,456	13,994,428	73,892,884
1897	52,050,782	10,309,209	62,359,991
1896	55,654,781	7,455,627	63,110,408
1895	65,409,806	.....	.....
1894	64,655,385	.....	.....

PRODUCTION BY STATES IN 1904.

Rank.	State.	Number of Operating Firms Re- porting.	Value.	Per cent. of total Product.
1.	Ohio	819	\$25,647,783	19.57
2.	Pennsylvania	529	16,821,863	12.84
3.	New Jersey.....	161	13,304,047	10.15
4.	Illinois	492	10,777,447	8.23
5.	New York.....	240	10,543,070	8.05
6.	Indiana	465	5,902,589	4.50
7.	Missouri	232	5,481,504	4.18
8.	California	121	3,624,734	2.77
9.	Iowa	327	3,460,853	2.64
10.	Kentucky	120	2,087,277	1.59
11.	West Virginia.....	64	2,074,549	1.58
12.	Georgia	103	1,920,936	1.47
13.	Maryland	63	1,872,057	1.43
14.	Kansas	69	1,843,630	1.41
15.	Virginia	99	1,736,392	1.33
16.	Massachusetts	87	1,729,058	1.32
17.	Michigan	168	1,714,513	1.31
18.	Texas	152	1,536,097	1.17
19.	Tennessee	110	1,435,785	1.10
20.	Wisconsin	159	1,390,994	1.06
21.	Minnesota	114	1,319,907	1.01
22.	Alabama	118	1,289,548	.98
23.	Connecticut and Rhode Island	43	1,215,609	.93
24.	Washington	26	1,200,919	.92
25.	Colorado	90	1,189,291	.91
26.	Nebraska	109	1,067,387	.81
27.	Louisiana	74	1,011,478	.77
28.	North Carolina.....	204	897,964	.69
29.	Mississippi	92	775,494	.59
30.	South Carolina	68	732,033	.56
31.	Arkansas	69	696,582	.53
32.	Maine	64	558,361	.43
33.	New Hampshire.....	35	479,985	.37
34.	Oregon	65	446,340	.34
35.	Utah	51	419,726	.32
36.	District of Columbia....	15	306,460	.23
37.	Montana	25	279,431	.21
38.	Indian Territory.....	22	268,926	.21
39.	Oklahoma	33	262,098	.20
40.	Florida	17	252,864	.19
41.	Idaho	43	173,597	.13
42.	Delaware	24	158,970	.12
43.	North Dakota.....	15	147,579	.11
44.	New Mexico.....	15	108,764	.08
45.	Vermont	12	100,153	.08
46.	Arizona	18	68,885	.05
47.	South Dakota.....	13	63,203	.05
48.	Wyoming	10	35,845	.03
49.	Nevada	5	25,820	.02
	Other states.....		a564,851	.43
		6,069	\$131,023,248	100.00

a Includes products which could not be separately classified without disclosing the operations of individual establishments.

CHAPTER XIII.

DISTRIBUTION AND PROPERTIES OF LIME IN MINERALS AND ROCKS.

Lime is one of the important elements in the rocks of the earth's surface, and ranks fifth in amount, being less than oxygen, silica, alumina, and iron.

According to Clarke, this element constitutes nearly 5 per cent. of the igneous rocks, and according to Van Hise limestone equals 1-20 of the total mass of the sediments with 5 per cent. of additional lime carbonate in the shales and sandstones. The estimate of T. Mellard Reade gives the thickness of limestones equivalent to a zone 528 feet thick around the globe. The total amount of lime carbonate in the oceans is given in the Monograph of Van Hise as 160,000,000,000,000 metric tons, and the sulphate of lime as 1,666,000,000,000,000 metric tons.¹

Lime occurs in nature in a variety of combinations as carbonate, sulphate, silicate, phosphate, fluoride, etc. It is also combined with other bases in the various silicate minerals.

Lime carbonate is the most abundant form, and when crystallized is known as calcite or aragonite. Calcite or lime spar when pure is transparent, colorless like glass. It cleaves into rhombs with a hardness of 3 in the Mohs scale of hardness (1 soft talc to 10 diamond), a little harder than the finger nail, but easily scratched with a knife, and has a specific gravity of 2.7. Through the presence of impurities, it is found in a variety of colors. Calcite is represented by the chemical formula Ca CO_3 with a composition of 44 per cent. carbon dioxide and 56 per cent. lime when pure. It is found in crevices, fissures and cavities, associated with limestones or other lime minerals.

Aragonite has the same chemical composition as calcite but occurs in elongated prisms. Its specific gravity is higher, 2.9, and its hardness ranges from 3.5 to 4. This mineral may be

1. The estimates in this section are taken from Van Hise's Monograph XLVII., pp. 941, 947, U. S. Geol. Survey.

PART II.

The Limestone and Lime Industry
of
West Virginia.

CHAPTER XIII.
DISTRIBUTION AND PROPERTIES OF LIME IN MINERALS AND ROCKS.

CHAPTER XIV.
THE LIMESTONES OF WEST VIRGINIA.

CHAPTER XV.
TECHNOLOGY OF LIME MANUFACTURE.

CHAPTER XVI.
THE USES OF LIMESTONE AND LIME.

transparent but is more often translucent, and when pure is colorless or white. It is found especially associated with gypsum and iron ores, and it forms the pearly layer of shells.

Limestone consists of lime carbonate, sometimes crystalline and often without crystal form, associated with various foreign impurities so that the percentage of lime carbonate is variable, ranging in the limestones of this State from 98.2 to 52.7 per cent., the impurities being magnesium carbonate, silica, iron, alumina, phosphorus, titanium, alkalies, and organic material. The different varieties of limestone are given below.

Massive limestone which occurs in strata of varying thickness and composition, is the rock ordinarily used for lime, cement, ballast, flux, etc. A fine, even-grained limestone suitable for stone engraving is known as lithographic stone, and is found in several places in this country, but the greater supply is imported from Solenhofen in Bavaria.

Hydraulic limestone has a considerable percentage of silica and alumina (10 to 30 per cent.) in addition to the lime carbonate. When burned it forms a cement which will set under water.

Chalk is a soft incoherent limestone formed mainly from shells of microscopic animals of the group Foraminifera. Large deposits are found in England and across Europe, in a belt nearly 1,000 miles long, also in central and western parts of the United States.

Oolite is limestone with granular texture composed of more or less rounded masses like fish eggs which give it the name oolite or egg-stone. The best known deposit in this country is the Bedford, Indiana, stone which is extensively used as a building and trimming stone.

Marl is a soft, earthy lime carbonate, and represents a lime sediment unconsolidated. It is found in lakes, swamps or stream valleys in many parts of the country from a few inches to 40 or 50 feet in thickness. It forms the basis of the cement industry in Michigan and there has the following composition:¹

	Light marl.	Blue marl.
Lime carbonate.....	93.75	91.34
Magnesium carbonate.....	2.42	0.77
Silica	1.19	1.20
Alumina oxide.....	0.55	0.55
Ferric oxide.....	0.25	0.40
Alkalies, organic matter.....	1.84	5.79

1. Geol. Survey of Mich., Vol. VIII., p. 247.

Marls are often described as impure lime carbonate deposits associated with high percentage of clay, but the Michigan marls, according to these analyses, are of high degree of purity with very small percentages of clay and other impurities.

Travertine is formed by the evaporation of water from springs containing lime carbonate in solution. In Yellowstone Park, according to Weed, it has been deposited to a large extent through the work of fresh water plants known as Algae.

Onyx marble is a variety of travertine often with a banded structure due to intermittent deposition, and capable of taking a high polish. It is found in a number of western states and is used for ornamental work in place of marble.

Stalactites and stalagmites are formed in caves, the former projecting from the roof and the latter from the floor, forming columns and pinnacles. The lime carbonate is deposited by evaporation of the water dripping from the roof. They possess a concentric structure and often reach large size.

Dolomite is a lime-magnesium carbonate rock where the lime carbonate has been partially replaced by the magnesium carbonate. In the pure crystal form it consists of 54.3 per cent. of lime carbonate and 45.7 per cent. magnesium carbonate. Dolomite forms massive strata like limestone and is then usually found in regions of mountain uplift. If the limestone contains less than 25 or 30 per cent. of magnesium carbonate and over 8 or 10 per cent. it is called a magnesian limestone. Limestones with over 30 per cent. of magnesium carbonate are usually called dolomites.

Marble is crystalline limestone which will take a high polish formed from ordinary limestone or dolomite by the forces of heat and pressure associated with metamorphism.

Lime sulphate occurs in hydrous form, gypsum; and without water, anhydrite. Gypsum is represented by the chemical formula $\text{CaSO}_4 + 2\text{H}_2\text{O}$, and when pure would contain 79.1 lime sulphate, 20.9 per cent. water. Its hardness is 2 and can be scratched by the finger nail, its specific gravity is 2.3, a cubic foot weighing 140 pounds. When crystallized it occurs in transparent plates and prisms cleaving into parallel leaves like mica except the plates lack elasticity.

Gypsum occurs also in solid rock ledges and in earthy form

When heated to 370° F. it loses part of the water forming plaster of paris which will set on the addition of water. The formula becomes $(\text{CaSO}_4)_2, \text{H}_2\text{O}$, calling for 93.8 per cent. lime sulphate and 6.2 per cent water. Plaster of Paris sets in a few minutes, so a retarder is added in the form of an organic preparation to delay the set for a number of hours, and the product is sold under the name of cement plaster which has become a formidable rival to the lime industry.

Lime plaster has been replaced to a large extent by hard wall gypsum plaster in many sections of this country. It has now become important in the lime industry to improve the product and by suitable preparation to form a plaster which can compete with the gypsum plaster. While gypsum does not occur in this State in sufficient quantity to be of economic importance, there are large deposits in Virginia, New York and Michigan. There are also some large companies in the State engaged in the preparation and sale of these cement plasters.

Anhydrite has the composition of gypsum without the water, its chemical formula being CaSO_4 . Its hardness is greater, 3 to 3.5, and its specific gravity is 2.8 to 2.9. When pure, anhydrite contains 41.2 per cent of lime, 58.8 sulphur trioxide, and when calcined it does not set on addition of water. It is formed from gypsum by the elimination of the water, a reaction greatly aided by pressure, and in the deep well samples in Michigan anhydrite is found instead of gypsum.

Lime silicate or Wollastonite has the chemical formula CaSiO_3 which would give the composition as 48.3 per cent. lime, 51.7 per cent. silica. Its hardness is 4.5, specific gravity 2.8. It occurs in tabular crystals or short prisms in granular limestones especially near granite contacts.

Lime phosphate or apatite is widely distributed in minute crystals in granites and occurs in large deposits in Spain, Norway, and Canada, associated with limestones. It is mined and used in manufacture of phosphate fertilizers.

Lime fluoride, fluorite or fluorspar occurs usually in the form of cubes often of marked beauty. When pure it contains 51 per cent. of lime and 49 per cent. of fluorine. Fluorspar occurs in veins associated with limestone and granites. It is mined in Kentucky, Illinois, Tennessee, and Arizona, for use as a flux.

Fourteen other minerals with lime as the base combined with arsenic, antimony, titanium, chlorine, etc., are given by Dana in his *System of Mineralogy*.

Lime is also found in a number of silicate minerals which are important rock forming constituents: 10 per cent. in hornblende; among the feldspars 5 per cent. in oligoclase, 12 per cent. in labradorite, 20 per cent. in anorthite, 18 per cent. in the scapolites, also in pyroxene, sphene, zeolites, epidote, and some garnets. Lime is found in varying percentages in the sedimentary rocks, shales and sandstones.

The specific gravity of a number of lime compounds is shown in the following table:

Calcite	2.7
Limestone	2.65
Dolomite	2.65
Lime oxide.....	2.3 to 3.1
Lime hydrate.....	2.078
Metallic lime.....	1.578
Lime oxide crystals.....	3.25

Origin of Limestone.

Limestones are of chemical and organic origin. Some writers have regarded the massive limestones, especially of the earlier geological periods, as of purely chemical origin, but the generally accepted theory is that most limestones are of organic origin.

The preceding paragraphs show that lime occurs in a variety of mineral forms and rock types, and that the total quantity of lime in the earth is very large. Lime carbonate is soluble in water, and the chemical analyses of spring, river, and lake water show a marked percentage of this compound. As the rivers flow to the ocean, they carry the lime in solution into these basins, and the enormous quantity of lime in the oceans has been stated above.

Ocean water contains 96.5 per cent. water; 3.5 per cent. of salts, of which over three-fourths is common salt; 0.34 per cent. is lime carbonate; 3.6 per cent. lime sulphate. If a basin or sea is cut off from the main ocean and the water evaporated, the salts would be precipitated, one of the early compounds to be deposited under these conditions being lime carbonate later consolidated into limestone of purely chemical origin.

Evaporating lakes would in a similar way form deposits of lime carbonate as chemical precipitates from solution. Deposits of lime carbonate are formed at the mouths of rivers. In the

Great Basin desert region of Utah and Nevada there formerly existed large lakes which have now decreased through evaporation to a series of small salt lakes. The lake deposits especially in the Nevada region are characterized by the large quantity of lime carbonate formed as a chemical precipitate.

Large deposits of lime carbonate are associated with the hot springs of Yellowstone Park, formed partly as chemical precipitate and partly through action of small plants, Algae.

The limestones of the early Archaean geological period before the fossil bearing strata, contain no undisputed evidences of life, and have therefore been regarded by T. Sterry Hunt as chemical precipitates, but even these non-fossiliferous limestones are classed by most geologists as organic, the fossils having been destroyed by the metamorphic changes that have taken place in these rocks.

It is thus seen that while in a number of local examples limestone has a chemical origin, most of the larger deposits have been formed through organic agencies, though their structure may have been later modified by chemical solution.

The various shell animals of the ocean, Crinoids, Mollusks, Foraminifera, with the Corals have built their shells and skeletons with carbonate of lime extracted from the water. With the death of these animals the lime structures accumulated on the ocean floor where they were ground and broken by wave action, and through course of time accumulated as lime debris mingled with silt, sand, and other impurities. By chemical solution, crystallization and cementation, the shells and coral skeletons were consolidated into rock, later raised by earth movements into land areas. The origin is thus primarily organic, but altered by chemical solution and redeposition, firmly cementing the particles together.

The composition of the coral structure and shells of mollusks are given by Dana¹ as follows:

	Coral.	Terebratula shell.	Oyster shell.
Lime carbonate.....	97.17	98.39	93.9
Lime phosphate.....	0.98	0.61	0.5
Lime sulphate.....	....	....	0.4
Magnesium carbonate.....	....	....	0.3
Water and organic.....	2.81	1.00	3.9

1. Manual of Geology, p. 72.

The formation of the limestone was very slow, according to Dana¹, it requires 5 to 10 feet of the fragmental lime deposits to make one foot of limestone rock. According to Le Conte the rate of formation of coral rock would be one or two feet a century where conditions were especially favorable. The formation of thick limestone strata has thus taken a very long period of time.

Origin of Dolomite.

A typical dolomite contains 54.3 per cent. lime carbonate and 45.7 per cent. magnesium carbonate, but as has been stated a limestone with 30 per cent. or more of magnesium carbonate is usually described as a dolomite, though it would be more correct to call such rocks dolomitic limestones, reserving the term dolomite for those rocks which have nearly the typical percentages of lime and magnesia.

The origin of magnesian limestones has been a subject of investigation and study for a very long time and three theories have been advanced, one of which is quite generally accepted.

The first theory that magnesian vapors escaped from the interior of the earth through fissures or volcanic vents forming by precipitation magnesia minerals and in connection with lime formed the dolomites. This theory is to be classed with many similar explanations for other rock and structure types belonging to a past history which today lacks supporters.

The second theory has been advocated by some very able scientists of modern times, and regards magnesian rocks as chemical precipitates from the old oceans. A sea containing lime and magnesia salts when evaporated would deposit these salts, and it was supposed the two salts would be deposited at the same time forming the double compound of lime and magnesium carbonate, which according to the experiments of Bischof mentioned later could not take place.

The third and generally accepted theory of origin of magnesian limestones is that of replacement. The rock was composed of lime carbonate formed by organic agencies, or in some cases through chemical deposition, and later a portion of the lime carbonate was removed while magnesium carbonate was deposited in its place in smaller or larger amounts, the quantity determined by

1. Loc. cit., p. 716.

a variety of factors, time, absolute and relative amounts of lime and magnesia in solution, and in the rocks, change in volume due to the reaction, and direction of movement of the solution.¹

Five groups of facts are given by Van Hise in support of the replacement theory:

1. There are no sea animals known that deposit more than a small amount of magnesium carbonate in their hard parts. Bivalve shells contain 0.5 to 1 per cent., corals less than 0.5 per cent. The magnesian limestones could hardly have been formed directly by organic agencies.

2. It has been stated that these limestones are chemical precipitates, and that while the sea is not now saturated with lime and magnesia, it might have been in the past when the dolomites were formed. There is no proof that the conditions in the past history of the seas were much different from the present. Further, Bischof found by experiment that in saturated solutions of lime and magnesia, the lime carbonate was largely precipitated before the magnesium carbonate was thrown down in any quantity, so the natural order would be separate layers of lime and magnesium carbonates rather than a mixture of the two.

3. There has accumulated a number of observations which can only be explained on the theory of replacement. Coral skeletons are composed of nearly pure lime carbonate, yet Dana found the limestone on the coral island of Metia containing 38 per cent. of magnesium carbonate. In magnesian limestone areas it is often found that the magnesia is more abundant near joints and faults, the natural courses of circulating waters.

According to Van Hise, limestones in regions of strong mountain movements with the consequent fracturing, are more strongly magnesian than limestones of the same age in less disturbed regions. He therefore reaches the conclusion that limestones are apt to be magnesian in proportion as there were favorable conditions for the entrance of solutions bearing magnesia.

4. Considering the world as a whole, the older a limestone formation the further advanced is dolomitization. Cambro-Silurian limestones are generally strongly magnesian and Pre-Cambrian limestones are usually completely dolomitized.

1. Van Hise, U. S. G. S. Mono. 47, p. 793.

5. The change of calcite to dolomite involves a contraction of 12.3 per cent. Most dolomites not subjected to strong orogenic movements are porous, which would be explained as due to the contraction in volume. The dolomites in mountain regions may have these openings closed by the later mashing and recrystallizing forces, so as to be quite compact.

Van Hise further gives the source of the magnesia in the sea as due to the magnesian minerals in the original igneous rocks, as micas, pyroxenes, hornblende, olivines, or from later secondary minerals as garnet, tourmaline, chlorite, etc.

The magnesia is removed from these minerals in solution, and part of it in the cycle of circulating waters finally reaches the sea. Chemical analyses of sea water show that the amount of magnesian salts is three times that of lime; so the replacement of lime by magnesia may have taken place in the sea while the limestone was still in the form of unconsolidated lime mud, or the change may have taken place after the limestone had been raised to form part of the land area, by the agency of circulating waters carrying magnesia.

Hall and Sardeson¹ have explained the origin of the dolomitic limestones in Minnesota as due to the gradual removal of lime carbonate in solution from the limestone resulting in a great reduction of thickness of the formation and an increased percentage of magnesium carbonate in the remainder of the limestone.

Doelter and Hoernes² explained the dolomites of the Tyrol which occur in layers alternate with the purer limestones and separated by sharp boundaries, as formed in arms of the sea more or less cut off from the ocean, where there was a great concentration of magnesia salts.

Origin of the Eastern West Virginia Dolomites.

In Jefferson and Berkeley counties both high calcium limestones and dolomites are found in belts trending northeast-southwest and usually highly tilted. The lines of contact of the two grades of rock are sharp often with no gradation of magnesia content from one to the other, while in a few places the two kinds of rock are separated by a belt of lower grade limestone containing 10 to 15 per cent. of magnesia. The dolomites are compact

1. Bull. Geol. Soc. America, Vol. VI., p. 167.

2. Jahrbuch der K. K. Geol. Reich. XXV., p. 293.



Plate XXI-a.—Bessemer Limestone Quarry, Martinsburg.



Plate XXI-b.—Crumpled Lower Helderberg Limestone at Cedar Cliff.

instead of porous in texture, and the purest limestone appears to follow closely the shale contact.

The geological history of the area may be stated briefly as follows: The lime sediment was deposited on the floor of the old Cambrian and Silurian oceans, and later covered by the mud in the Silurian sea, now represented by the Martinsburg shales. The whole mass of sediment was raised into land and consolidated into rock. The rocks were thrown into a series of folds broken and faulted at the close of the Paleozoic division of geological time. During all this long period of time and since, these rocks have been greatly eroded, the tops of the folds are gone, leaving the highly tilted rocks and shale masses here and there.

At some time in this history there was a partial replacement of the lime carbonate by magnesium carbonate in the limestone. Not all the rock was changed, and in some parts of the formation the replacement was more complete than in other portions.

This change must have taken place before the sediments were raised from the sea, or after the rocks formed part of the land area. If at the former time, under a normal condition of uniform deposition of the sediments through a long period of time, since lime sediments accumulate very slowly, there should be a uniform percentage of magnesia through the whole formation.

There might be a possible explanation for the replacement at this epoch of the history of these rocks in the fact that the great thickness of this limestone formation (2,500 feet) would necessitate a sinking sea floor. At certain periods this floor may have remained nearly stationary with a greater evaporation of water resulting in increased percentage of the salts, and the sediments being exposed to the action of this water for a long period, would have the lime replaced by magnesia, while later by further sinking and influx of water the replacement would be interrupted and the lime sediments remain pure. According to this theory, the dolomitic layers would represent breaks in the normal order of deposition. There is no evidence in the rocks to substantiate this explanation, and other theories would seem to be more reasonable.

Over the limestone is now found the remnant of the Silurian sediments in the Martinsburg shales, over 700 feet in thickness. These mud sediments represented a great change in the physical

condition of the old Silurian sea. The floor was probably sinking slowly, with shallow water conditions, and an inflow of silt laden waters from the land area. The cause of the shallow water near the land area was due either to a retreat of the sea or the formation of more or less enclosed areas with greater water evaporation. Under the former condition there would be no explanation of the deposition of magnesium carbonate. Under the latter the surface layers of lime sediment to a certain depth would probably undergo the process of replacement, giving magnesian limestones above and purer rock below. When the rocks were later folded and eroded, the magnesian layers of the top of a single fold would form two belts separated by the lower high calcium layers, and the arrangement would be repeated in the next fold. The upper layers would be next to the overlying shales, but these are the high calcium rocks of the Martinsburg area. As the folds of this area are replaced from the dip of the rocks there appears to be a rather uniform relation of the upper layers being purer limes than the lower.

The explanation that there was in the later Silurian sea a series of elongated enclosed basins where evaporation was greater and conditions especially favorable for the replacement of lime by magnesia would necessitate for this area, the assumption that there was a large number of parallel basins, 50 to 150 feet wide and lenticular in form, which does not seem probable. There seems to be little support for any theory of replacement of the lime by magnesia in these sediments while under the sea.

Assuming the change took place later, the replacement occurred in the long time before the mountain uplift, during the uplift, or afterward.

In the earlier history of these rocks before the mountain uplift, the limestones were covered with shales, 700 feet or more in thickness and compact, so that downward circulating waters would have little effect on them. It is doubtful if this mantle of shales was wholly removed during the Paleozoic, and if so in places, the change would be found in the surface layers.

If the replacement has taken place wholly since the uplift, it is difficult to explain the occurrence of the dolomite in certain belts, and with the sharp lines of contact with pure limestone in areas where both would be brought equally under the influence of the circulating waters. Further, under normal conditions of

pressure limestones are never changed to pure dolomites. Great pressure is necessary to cause a replacement of lime by magnesia to form a true dolomite.

At the close of Paleozoic time after the coal measures were formed and the Permian series of rocks, there came a period of mountain making when the rocks of this area were folded, crushed and faulted. The replacement of about half of the lime carbonate by magnesium carbonate results in a contraction of 12.3 per cent. With increased pressure this change would be more complete, if the solutions were available. The dolomites of this area of the State have nearly the theoretical proportions of lime and magnesium carbonates. The crumpling and resultant fracturing of the rocks would give better access to circulating waters especially along the lines of fracture or faults.

Near Shepherdstown, where the rocks are highly tilted and crumpled nearly all the limestone is magnesian. The Shenandoah limestone near the fault line of the Antietam sandstone contact is almost a pure dolomite. Near Martinsburg and Charles Town, where the folds are sharp and broken, dolomites are found, while in the sections of broad, unbroken folds, the limestone is low in magnesium carbonate seldom reaching ten or twelve per cent. At Cedar Cliff in Mineral county, where there is similar folding and crumpling, the limestone of Lower Helderberg age is highly magnesian but not a true dolomite. Under such conditions there must have been great pressure on the rocks and channels opened for circulating waters.

Near the shale contact, even with high tilting and apparently similar conditions to those outlined above, the rock is an exceptionally pure limestone with less than one per cent. of magnesia. In such areas the overlying compact shales have doubtless protected the rock from the magnesia bearing solutions, and the rock may have been rendered so compact by the pressure that solutions could not readily pass into the limestone.

The Martinsburg shales contain an average of 2.65 per cent. of magnesium oxide, but the decomposed and weathered surface shales contain only 1.2 per cent. Downward circulating waters would have magnesia in solution derived in part from the shales, and in part from other rocks more or less distant from the limestone area. According to Van Hise, it is a chemical law that solid lime carbonate in contact with a solution containing lime and

magnesia, will have part of the lime replaced by magnesia, and the interchange will take place more rapidly where the percentage of magnesia is low in the rock, but the reaction will be very slow in highly magnesian limestone except under the influence of pressure.

Whether the magnesian solutions in this area came from above or below is difficult to determine from the evidence at hand. There appears to be no metal deposition and no evidence of heated water. While upward circulating waters may have been present, their presence would not seem to be required to explain the replacement.

As a summary of the discussion above, the origin of the eastern West Virginia Shenandoah dolomites and magnesian limestones is regarded by the writer as due to the replacement of lime carbonate in part by magnesium carbonate brought in solution in downward circulating waters, a reaction which took place especially at the time of the Appalachian mountain uplift at the close of the Paleozoic era of geological time.

Lime Oxide (CaO).

Lime oxide when pure is a white solid, without crystal form, infusible and non-volatile at temperature below 3000° C. The commercial oxide is more or less tinged with color due to impurities present.

The metallic lime free from oxygen may be made by electrolysis of fused lime chloride, or more readily by heating seven parts of the iodide of lime with one part sodium in a crucible. The metal is yellow in color, soft, with a specific gravity of 1.578. It is said to be both malleable and ductile, and does not tarnish in dry air. If heated in a current of air or oxygen the metal burns into lime oxide with a very brilliant light.

Lime oxide in a very pure form may be obtained by heating the nitrate of lime $\text{Ca}(\text{NO}_3)_2$. The resulting lime is amorphous, but if heated to 2500 degrees C., forms cubical crystals with a specific gravity of 3.25, and if heated to 3000 degrees centigrade, fuses.

The lime oxide is usually obtained by burning rocks composed mainly of lime carbonate. The carbonic dioxide is driven off leaving the lime oxide or quick lime. This process of burning



Plate XXII.—Big Spring in Greenbrier Limestone, Marlinton.

consists of two stages according to Reid:¹ The first stage in which the water is evaporated from the stone and the organic matter is burned, called sometimes the "water smoking" period, or "vaporization" period; the second stage in which the carbonic dioxide is removed, "decarbonization" period.

In economical lime burning in the intermittent kilns, the fuel is added slowly and in small quantity during the first stage of burning until the vapor ceases to rise in any quantity, then the fires are increased to bring the rock to the proper temperature for the expulsion of carbonic dioxide. A failure to follow this method of firing causes a waste of fuel and also breaks the lime into small pieces by the formation of steam within the rock. In the draw kilns less trouble is required in raising the temperature of the rock, since the rock in passing from the top of the kiln to the highly heated zone is gradually raised in temperature, the water being mostly forced out before the rock reaches this highly heated zone.

The amount of lime formed from a given quantity of stone depends on the purity of the limestone. One hundred pounds of pure lime carbonate would yield 56 pounds of lime, 44 pounds of carbonic dioxide being driven off. Limestones in nature are more or less impure, the more common impurities being magnesia, silica, alumina, iron, sulphur, alkalies, and organic matter, as illustrated by the following analyses of a very pure, a quite impure limestone from this State, and a dolomite:

	Martinsburg.	Clarksburg.	Millville.
Lime carbonate.....	98.98	56.54	54.00
Magnesium carbonate.....	0.43	12.31	46.00
Silica	0.58	17.18	0.30
Alumina	0.13	7.06 }	0.57
Iron oxide.....	0.75	4.94 }	
Titanium	trace	0.19	....
Sulphur	0.00	0.66	....

Magnesia, when present in any considerable amount, appears to make the rock burn easier, and changes the character of the resulting lime, making it slow setting and generating very little heat on hydration. It has also been claimed to give the lime some hydraulic properties, which view is not upheld by experiment.

1. Portland Cement, p. 243.

Silica may be present in the form of small grains of sand, or in the form of chert or flint nodules of larger or smaller size. It may also be present in the form of silicate minerals, mica, feldspar, etc., or combined with alumina in the form of clay. When present in small quantities it is probably inert. In larger quantity it may unite with lime oxide at the high temperature of the kiln forming a flux which coats the surface of the lime nodules with a clinker and prevents their complete calcination. Such masses of clinker if left in the lime form a troublesome impurity as later the slaking of the protected interior may cause defects in the wall plastered with such lime. The larger masses of clinker are removed by hand picking.

Alumina may be present in small quantities in aluminate minerals, but more commonly in the form of clay, and is usually present in small quantity which is practically inert. Large percentages of alumina and silica give the lime hydraulic properties.

Iron may change the color of the lime if present in any quantity, and it also acts as a flux. Alkalies are fluxing agents in the lime, and if present in any quantity will cause trouble by clinkering the material.

Sulphur has a tendency to darken the lime and may form sulphates. It is present in form of sulphide as pyrites, or as a sulphate in the mineral, gypsum. Sulphur is rarely present in sufficient quantity to injure the lime. Organic matter is very often present in limestones in small quantity. It gives the color to some gray and black limestones and is completely removed in the process of calcination of the lime.

Classification of Limes.

Limes are classified according to the kind and amount of impurities into five groups: Fat limes, lean limes, magnesian limes, hydraulic limes, hydraulic cements. The first two groups are sometimes united under the terms, pure limes, calcareous limes, high calcium limes.

Fat limes or rich limes contain less than 10 per cent. of impurities. They usually are quick setting, but some are slow setting, the time of setting depending on physical as well as chemical conditions. In the process of slaking they usually generate a high degree of heat and are called hot limes. During this pro-

cess they expand two to three times their original bulk. On the addition of water, they form a paste which on hardening is accompanied by high shrinkage which must be counteracted by the addition of sand. As the percentage of impurities is low, this grade of lime will carry more sand than poorer grades, so it is sometimes known as strong lime.

Lean or poor limes contain more than 10 per cent of impurities, consisting of silica, alumina, iron, etc. Gilmore in his classification places the magnesian limes in this class. The lean limes are not made except in sections where high grade limestone cannot be obtained, or where it is to be used for fertilizer. Such limes slake slowly and will not carry as much sand as the preceding group.

Magnesian limes are made from limestones containing 10 to 15 per cent. magnesium carbonate or more. The typical magnesian limes would be made from dolomites. In slaking they produce but slight elevation of temperature, the expansion is less than in the fat limes, and they are slow setting. Many of these limes have a low percentage of silica, alumina, and iron impurities, less than 1 per cent. in the dolomitic limes of the eastern part of West Virginia.

Magnesian limes are preferred by the workmen in many sections of the country, especially where the calcareous limes are quick setting. The mason using magnesian lime mortar can place two to three times as many brick in a single spread of mortar as he could by use of a quick setting lime. The plasterer can usually make a smoother wall, and the magnesian lime when pure is as white as any other lime. One of the arguments long used against magnesian mortars was low strength of mortar which seemed to be shown on short time tests. In tests on strength of mortar made from pure limes and magnesian limes for 30 and 60 days the former showed a greater strength, but after a six months and a year tests, it has been found that the magnesian mortars equal and in some cases surpass the strength of pure lime mortars.

Each group of mortars is popular in sections of the country and usually the one is preferred which is made in that section, for when a plasterer or mason becomes accustomed to the use of one he finds trouble with the other until he becomes experienced in its use. The demand in the Mississippi valley is for pure limes, and the same is true in West Virginia, Virginia, and Maryland.

to a large extent, while in Ohio and eastern Pennsylvania the demand appears to be for magnesian limes. For building work, both groups of lime are good and will be used, for certain chemical and industrial uses the lime must have a high percentage of calcium oxide, and magnesium may then prove an injurious impurity.

Hydraulic limes are made from limestones containing 15 to 20 per cent. of silica and alumina. They may contain magnesia, but if so this element appears to be inert. Such limes slake on burning and mortars made from them will set under water.

Hydraulic cements are made from similar limestones to the last, but with a higher percentage of silica and alumina. On burning they form a clinker which must be ground to a flour before it can be used.

Setting and Hardening of Lime Mortar.

When water is added to lime it forms a lime hydrate, and on exposure to the air, the surplus water is evaporated. It has been generally inferred that the formation of the hydrate was complete when moisture disappeared from the lime mass and the set of lime has been described as the drying of the lime by removal of the surplus water added.¹ According to the researches of Chatelier² the slaking of lime is divided into four stages: 1. Simple absorption of water. 2. The mixture is warmed by contact and by heat of the chemical action taking place, and a portion of the added water is evaporated. 3. The mass cools and moisture is fixed by the silicates, although some of the free lime still remains unslaked. 4. The unslaked lime removes this water from the silicates and becomes completely hydrated.

The setting of lime may then be considered as due to the removal of the surplus water and the complete formation of the hydrate. The removal of all the moisture by evaporation and the combination of water with the lime oxide would bring the particles into close contact forming a weak bond by cohesion, constituting *the set of the plaster*. The time required will vary with the kind of lime, amount of impurities, amount of water used, and the air temperature. In some limes the reaction would be com-

1. Portland Cement, Reid, p. 59.

2. Monit. Ceramique, Vol. XXIX., Nos. 8, 10, 11, quoted by Frasc, Min. Industry, VII., p. 496.



Plate XXIII-a.—Snowflake Lime Kiln Near Fort Spring, Greenbrier County.



Plate XXIII-b.—Old Natural Cement Kiln (1830), Shepherdstown.

plete in a few minutes while in magnesian limes it may be a few minutes to several hours before the set is complete. In very lean limes or poorly burned limes, the hydrate formation may not be complete for days, or it may not take place with any length of time. After the set is well started any movement of the plaster will weaken the bond and injure the work.

The *hardening of lime plaster* is due to the absorption of carbonic dioxide from the air by the lime hydrate forming a carbonate, and the plaster thus tends to pass back to its original chemical composition. This change begins on exposure to the air but requires a considerable length of time before it can be measured. The action continues for years and probably is never completed. Old mortars have been analyzed and show high percentages of lime carbonate.

The strength of lime mortar is determined by the process of hardening and so increases with time. This fact is proved by the following table of tensile strengths in pounds per square inch by George S. Mills,¹ which also illustrates the greater strength of magnesian limes after five months' exposure:

	High calcium lime.	Magnesian lime.
After 4 weeks.....	30 2-3 pounds	
After 8 weeks.....	36 2-5 "	28 5-6 pounds
After 3 months.....	39 1/4 "	37 1-6 "
After 4 months.....	39 "	51 "
After 6 months.....	50 5-6 "	83 "
After 1 year.....	44 3-5 "	92 5-6 "

1. Municipal Engineering, Vol. 28, pp. 4-7; 1905, quoted by Eckels Cements, Limes, and Plasters, p. 122.

CHAPTER XIV.

THE LIMESTONES OF WEST VIRGINIA.

COAL MEASURES.

Dunkard Series:

Windy Gap limestone.
Nineveh limestone.
Washington limestone.

Monongahela Series:

Waynesburg limestone.
Uniontown limestone.
Sewickley limestone.
Redstone limestone.

Conemaugh Series:

Upper and Lower Pittsburg limestones.
Clarksburg limestone.
Elk Lick limestone.
Ames or Crinoidal limestone.
Upper Cambridge limestone.
Lower Cambridge limestone.
Mahoning limestone.

Allegheny Series:

Upper Freeport limestone.
Ferroferous or Vanport limestone.

Kanawha Series:

Two Mile limestone.
Campbells Creek limestone.
Cannelton or Stockton limestone.
Eagle limestone (Black Marble).

LOWER CARBONIFEROUS.

Greenbrier limestone. /

SILURIAN.

Lower Helderberg limestone.

Shenandoah limestone.

The use of limestone for lime, furnace flux, and ballast, has caused quarries to be opened at various places in West Virginia, and in some sections, especially in the Panhandle of the eastern part of the State, has resulted in large business operations. Over a larger area of the State the limestones are at the present time only used on a small scale for a limited local trade and their value is almost unknown.

The rapid development of the American Portland cement industry in the past few years has led to inquiries concerning the available limestones in the different parts of the country. The State of West Virginia contains a variety of limestones of variable thickness and quality, and it has been deemed advisable to collect into one chapter the available information on this subject. Most of the data for this chapter has been collected by the Survey during the past two field seasons especially for this purpose. Some of the information has been obtained in connection with the Survey investigations along other lines. Wherever data on coal measure limestones have been found in Dr. I. C. White's coal report, volume II., of this series, they have been incorporated in this chapter.

All the geological series of the State contain more or less limestone, but there is a marked difference in the distribution of the limestones in the northern and eastern parts of the State as compared with the southwestern area. In the highest series of rocks in the State, the Dunkard, the limestones found in the northern area with one or two exceptions thin away before reaching the Little Kanawha river into nuggets of lime held in masses of marly red shales, while the sandstones thicken southward.

In the Monongahela series of the northern part of the State nearly one-half of the rock material is limestone, but followed south from Harrison, Taylor, and Lewis counties, the limestones practically disappear and are replaced by red shales, while the

sandstones become more massive. According to Dr. I. C. White¹ no marine fossils have ever been discovered in any of the limestones of the Monongahela series and everything indicates that the deposits are of fresh water origin.

The Conemaugh series consists of an upper part with soft red marly shales and thin limestones with two or three massive sandstones; and a lower part of massive pebbly sandstones. The Allegheny series at the north has a number of limestones and the Kanawha series at the south has a few thin limestones. The limestones of the Pottsville series are not well developed in West Virginia, while the Lower Carboniferous has a thick belt of limestone across the State north to south. The Devonian and Silurian limestones are massive in certain areas in the State. The description of these various limestones in the State will be given beginning with the lowest geological horizon, the Cambro-Silurian found in the extreme eastern portion.

Shenandoah Limestone.

The Shenandoah limestone found in the Valley of Virginia was named by Rogers the Valley limestone or the No. II. of his series. Rogers in his Geological Survey reports from 1835 to 1840 calls attention to the distribution of this limestone and its value for the manufacture of natural hydraulic cement and agricultural lime.

The Shenandoah limestone contains a few fossils of Lower Cambrian age in its lower portion, and in the upper part contains fossils of Lower Silurian age. The line between the two formations cannot be drawn as a large part of the rock is without fossils, so the limestone is usually described as of Cambro-Silurian age.

This limestone belt follows the Shenandoah valley from Maryland across Jefferson county and a large part of Berkeley, then through Virginia into Tennessee with a few outliers in Pendleton and Hardy counties, West Virginia. Its width averages about 20 miles. The limestone area is marked by large orchards and rich farming lands and has long been famous for its fertility.

The limestone varies in color from a light gray through a dark blue to a black. While the black limestone appears to the

1. W. Va. Geol. Survey, Vol. II., p. 125.

eye to be the most impure, it is found on analysis to be high in carbonate of lime, the dark color being caused by organic material. The rock varies in chemical composition from 99 per cent. pure to dolomites of almost theoretical composition. The general trend of the formation is 25 to 30 degrees east of north. It is composed of a series of belts with the same general trend which for considerable distances are nearly constant in composition. The belt of high grade rock over 95 per cent. carbonate of lime was traced nearly ten miles with varying width. On both sides of this belt are the limestones with lower percentage of lime, while lenticular bodies of dolomite occur through the formation. The rocks are tilted at high angles and are much folded.

The limestone weathers to a red clay which varies in depth, reaching 20 to 30 feet in places. This clay has been used at Charles Town and Shepherdstown in the manufacture of brick. The thickness of the limestone is given by the United States Geological Survey as about 2,500 feet. The depth of the rock is not known but quarries worked to a depth of 90 feet do not reach the bottom. The Martinsburg shale of Silurian age forms belts in the limestone area especially near Martinsburg.

Development.—The Shenandoah limestone has been opened in a number of large quarries in both Jefferson and Berkeley counties where it is used in the manufacture of lime, railroad ballast, and the high grade rock and dolomite are shipped to Pittsburg and other iron and steel centers for flux.

Near Charles Town the limestone has been opened in small quarries for building stone and for rock used on the county roads. These quarries show a face of about ten feet as opened, and the rock is crushed in a portable crusher operated by a small engine.

At Millville the Standard Lime & Stone Company, owned by Baker Brothers, of Baltimore, opened a quarry in May 1901 in the dolomite. The face of the quarry runs north and south and the rock stands nearly vertical with the dip to the east. The quarry at the present time is worked with two benches, the upper face is 30 feet to 45 feet in height and the lower about 20 feet, giving a total height to the quarry of nearly 70 feet. The rock near the center has a bluish color, becoming very much lighter toward the ends of the quarry. The rock is cut by joint planes nearly horizontal and by vertical joints. The working quarry is one-half mile from the B. & O. railroad, while the old quarry is

near the railroad and has been abandoned. Red clay seams break down into the limestone and at one place have filled in the space to the bottom of the quarry, separating the old from the new quarry. The rock is crushed in a No. 7 Gates crusher and about 20 cars are shipped a day and used at Pittsburg in open hearth steel reduction.

The chemical composition of the rock is shown by the following analyses:

	New Quarry.	Old Quarry.
Lime carbonate.....	54.72	55.00
Magnesium carbonate.....	43.18	45.00
Silica	0.05	0.40
Iron and alumina.....	0.89	0.41
Phosphorus	0.01	
Sulphur	none	
Alkalies	0.15	
	99.00	

Across the Shenandoah river from Millville, the Harpers Ferry Lime Company has opened up a large tract of limestone land during the past summer (1905). The rock has been tested over an outcrop three-fourths of a mile long. A number of years ago the Becker Brothers operated a lime kiln at this place, and the present company has built three new Shoop lime kilns with 350 bushels daily capacity each. They have also installed two Champion crushers for ballast. The company is composed of Pittsburg men with abundant capital to make this a very productive center. The river will probably be bridged at this point, giving connection with the Baltimore & Ohio.

The rocks in this area vary from high grade limestone, 97 per cent. pure, to dolomite. Magnesian limes or pure limes can be placed on the market and shipped in all directions. Within a mile on the Wetzell farm is a large deposit of calcareous marl which would be available as well as these high grade limestones for the manufacture of Portland cement as described in another chapter of this report. The composition of the limestones at the quarries of the Harpers Ferry Lime Company is given in the following analyses:

	Dolomite.		Limestone.
Lime carbonate.....	55.00	54.00	92.96
Magnesium carbonate.....	45.00	46.00	4.62
Silica	0.30	0.53	1.70
Iron and alumina.....	0.57	0.47	1.29

At Engles' Siding, the Baker Brothers have three patent draw kilns, but the rock is shipped from their Bakerton quarries. At this same station the O. J. Keller Lime Company, also known as the Potomac Lime Company, of Buckeystown, Maryland, has a large lime plant and quarries opened in 1883. There are four patent draw kilns each with a capacity of 300 bushels a day; and five stone pot kilns each with a capacity of 325 bushels used in the manufacture of agricultural lime. The patent kilns are of the Decker pattern with three furnaces to the kiln, and use coal as fuel. It requires about 7,000 pounds of coal to burn 325 bushels of lime in 24 hours. The kilns are drawn every two hours and the lime is packed in barrels holding two and a half to three bushels. The lower grade rock is burned in the stone kilns where the stone and coal are placed in alternate layers, the resulting lime is darker in color than the building lime and is sold through the country for fertilizer.

The stone has a cover of red clay 6 to 15 feet in depth and the present quarry face is 30 feet. The upper ten feet is more irregular than the lower and near the top is in rounded boulders, so that it is not used for commercial lime. The lower twenty feet of blue limestone is now used for the higher grade lime. The quarry has been worked back nearly 1,500 feet from the Baltimore & Ohio main line.

The new Potomac quarry of the Keller Lime Company is located three-quarters of a mile west of the lime quarry at Engles and was opened in September 1904. The limestone is used wholly for ballast and is crushed in two Gates crushers, No. 6 and No. 4, and one Champion crusher. The daily capacity of these crushers is 400 cubic yards, and about 200 cubic yards represent the present output.

The rock is worked in a 20 to 25-foot face and is blue in color. The cover of four to seven feet consists of buff shale, irregular limestone nodules and clay. The limestone is broken by several belts of hard cream-white shales which are 20 to 60 feet wide and have a northeast and southwest trend. The blue limestone between these belts is 20 to 30 feet in width. To the west of the first quarry the shale belts are smaller and even disappear. The bottom of the quarry is 75 feet above the railroad track so that a 100-foot face can be worked to the track level.

There are 180 acres in this tract and the cover is thin over most of it. The shale has been analyzed and appears to be a magnesium aluminum silicate. It has the appearance of a sericite mineral and is much crumpled. Small belts of nearly white limestone are found near the east end of this quarry.

Chemical composition :

	Blue limestone.	White limestone.
Lime carbonate.....	92.27	98.21
Magnesium carbonate.....	3.18	0.86
Silica	1.18	0.02
Iron and alumina.....	1.60	0.75
Sulphur	0.51	0.09
Phosphorus	0.08	0.007
	98.82	99.937

The composition of the white shale or slate in the new Potomac quarry is:

Silica	42.95
Alumina	9.13
Ferrous iron.....	1.00
Ferric iron.....	1.02
Magnesia oxide.....	12.15
Lime oxide.....	11.40
Sodium	0.39
Potassium	5.50
Water	2.02
Titanium	0.37
Phosphorus	0.77
Sulphur	none
Loss on ignition.....	13.15
	99.85

At Bakerton, northeast of Engles, is located the Bakerton lime plant of the Standard Lime & Stone Company, also known as the Washington Building Lime Company. The quarry was opened about twelve years ago, and the rock is burned into lime at Bakerton and also at the kilns at Engles. There are twelve stone pot kilns holding 300 bushels each, used for agricultural lime and twelve patent steel draw kilns six feet in diameter and twenty feet high each with a daily capacity of 250 bushels. Each kiln has three furnaces built out from the kiln. Six of the kilns have air blower attachments and use coal fuel, while in the other six kilns coal and wood are used.

The quarry located near the lime kilns has been worked to a depth of 50 to 60 feet, the kilns being located at a level of the top of the quarry, and the rock hauled up incline tracks by cable.

The face of the quarry runs north and south and the rock dips to the west. The cover of red clay varies from 2 to 20 feet in thickness, being thickest at the ends of the quarry. The limestone is hard, compact, and crystalline. The lower twelve feet of the quarry contains numerous calcite streaks and is not used as it is regarded as impure. The next ledge of 12 to 15 feet above is blue in color and used with the next 10-foot ledge of light colored limestone. Under the red clay cover is a five foot ledge of hard blue limestone not used for commercial lime. The rock at Bakerton and Engles makes a very white, strong lime which finds a ready sale.

The limestone at this quarry has the following composition:

Lime carbonate.....	95.55
Magnesium carbonate.....	2.44
Silica	0.12
Iron and alumina.....	1.01
Sulphur	0.15
Phosphorus	0.02

99.29

Knotts quarry, near Bakerton, is in high grade lime and the rock is shipped to Washington city where it is burned into lime. At Kearneysville, eight miles east of Martinsburg, the Standard Lime & Stone Company has a quarry for railroad ballast opened fourteen years ago, furnishing ballast especially for the Baltimore & Ohio railroad. The rock is crushed in two Gates crushers. Nos. 4 and 6, with an output of 600 yards a day or 15 to 20 cars. One yard of this stone weighs about 2,320 pounds.

The quarry is 60 feet deep with a red soil cover of 3 to 20 feet, and is worked nearly 500 feet square. The lower 20 feet is very solid high grade rock and is hauled in cars up an incline track to the crushers. The face shows joints running northwest-southeast, cutting to the bottom of the quarry, with other joint planes at right angles. The rock stands nearly vertical. In the quarry are eighteen tracks leading to the foot of the incline and the cars are hauled by mules to this incline. The lower solid rock of the quarry was sampled and showed the following composition:

Lime carbonate.....	89.91
Magnesium carbonate.....	3.18
Silica	3.81
Iron and alumina.....	2.00
Sulphur	0.25
Phosphorus	0.12

99.27

The Shenandoah limestone has been opened in one or two small quarries near Shepherdstown and at the natural cement quarries and will be described in a chapter in the part of this report on cement.

In the vicinity of Martinsburg are several large quarries. The Standard Lime & Stone Company opened a quarry at south edge of town twelve years ago and has since opened a number of others to the south of the first, working on high grade limestone which is shipped to Pittsburg for flux. From 40 to 60 cars are sent out from these quarries daily, and part of the rock is sent to their ten lime kilns located on the other side of town which have a capacity of 1,800 bushels a day.

One quarry has been worked to a depth of over 90 feet but encountered a strong spring of water which flooded the quarry, causing its abandonment. The lower 60 feet of this quarry was good rock and the lower 25 feet was considered high grade, which is proved by the analysis given below. Joint planes run north and south and also at right angles. The rocks are inclined at an angle of almost 90 degrees, the dip being to the east. The present line of quarries is about two and one-half miles in length. In the lower quarry the rock is crushed and screened to a flour used by the glass works, and the company has opened a new quarry on the other side of town near their lime kilns. The Baker Brothers were the pioneers in this limestone industry of the eastern part of the State and have built up a large and strong business. Their quarries are the most extensive of any in the State and they have large limestone land holdings near Martinsburg that have not yet been opened.

The composition of the lower rock in the quarry near town, and that of the rock from the Bessemer quarry of the Martinsburg Limestone Company, located five miles west of town, are given in the following table:

	Baker Bros.	Bessemer Quarry.
Lime carbonate.....	95.44	95.18
Magnesium carbonate.....	2.51	3.47
Silica	0.60	1.14
Iron and alumina.....	0.69 }	
Sulphur	0.12 }	0.81
Phosphorus	0.05	....
	99.41	100.60

The Martinsburg Limestone Company, known before January 1904 as the Bessemer Limestone Company, opened a quarry five miles west of town five years ago (shown in plate XXI). The quarry face is 50 feet with 5 to 15 feet of cover, and the rock is high grade. It is crushed in a No. 8 Austin crusher, and about ten cars a day are shipped to Pittsburg for use as flux. Three quarries are opened with a width of face 125 feet in the first one, over 200 feet in the second, and the third is being opened this year (1905). Some of the rock runs 99 per cent. pure and it is all high grade in the present working quarries. The composition of the rock is as follows:

	No. 151.	No. 162.	No. 165.
Lime carbonate.....	89.66	97.96	95.18
Magnesium carbonate.....	8.98	2.01	3.47
Silica	1.07	0.49	1.14
Iron and alumina.....	0.55	0.36	0.81

No. 151 is from the old quarry, No. 162 from the quarry opened this year, and No. 165 from the main working quarry.

The McDowell Lime Company quarry is located at the north-eastern edge of town, about one mile from the center. It was opened in 1873 and is used for building stone and lime. The company has one six-foot draw kiln with 160 bushels daily capacity, and two old stone kilns no longer in use.

The rock in the quarry stands nearly vertical and is worked to a depth of 30 feet with a red earth cover three to ten feet in thickness. White streaks of crystallized lime or calcite occur through the rock, which is blue in color becoming lighter colored near the top.

Near Bunker Hill, eight miles south of Martinsburg, is located the Kline quarry opened five years ago, two miles from the town. There are two stone kilns fired from below with wood, each holding 500 bushels. It requires one cord of wood to burn 35 bushels of lime, coke was tried but was not successful. The quarry is within one-half mile of the Cumberland Valley railroad and shows 30 feet of face as opened. The rock is blue in color with white calcite streaks in places, and dips east at an angle of 45 to 50 degrees. The vein of high grade rock appears to be nearly 300 feet wide near the quarry. Along Mill creek near the quarry is a deposit of marl two or three feet deep which is reported as much thicker at other places in this region.

The composition of the limestone and marl is found by analysis to be:

	Quarry.	Marl.	200 feet west of quarry.
Lime carbonate	97.17	90.16	97.05
Magnesium carbonate.....	1.26	1.30	2.63
Silica	0.60	4.41	0.59
Iron and alumina.....	0.46	2.18	0.47

A more complete description of the limestone near Martinsburg is given in Chapter V. of Part III.

Lower Helderberg Limestone.

The Lower Helderberg limestone has a thickness of 500 feet and outcrops through Morgan, Mineral, Hampshire, Hardy, Grant and Pendleton counties in narrow belts. It has been named by the United States Geological Survey, the Lewiston. This rock is well exposed in high cliffs near Keyser and Cedar Cliff, where it is highly inclined. Certain portions of this limestone have been used in the manufacture of natural cement at Potomac and Cumberland, Maryland, and at Cedar Cliff, this State. The description of the rocks at Cedar Cliff is given in the section on cements.

At Keyser the Standard Lime & Stone Company has a large quarry one mile east of town on the Baltimore & Ohio main line, which was opened five years ago for ballast. The rock is crushed in two Gates crushers and twelve cars are loaded daily. The quarry face is about 800 feet long from east to west and 200 feet vertical. The rock dips west, but is nearly vertical with practically no cover. The joint planes running north and south extend from the top to the bottom of the quarry and cause the rock to break down, leaving the large smooth walls which make a striking feature in this quarry. There are also horizontal joint planes which are not continuous for any distance. At the west end of the quarry is a flint stratum 18 feet in width which breaks into layers two inches to one foot thick. The rock varies in the quarry and a section taken near the center shows in width going east, 10 feet shaly limestone, then 3 feet of blue shaly limestone, 6 feet blue, 12 feet black, 10 feet spotted black and white, 28 feet gray, 15 feet of limestone with irregular fracture breaking up into small blocks. If followed to the west from the center there are 40 or 50 feet of blue limestone which show by analysis a very pure rock.

The same rock is found in the Keyes quarry near the county road, one-half mile east of town. This opening is much smaller but shows a variation in the physical appearance of the rock. The height of the quarry is about 50 feet. One stratum is light colored and was burned for lime some years ago. It is 20 feet in width and is a high grade limestone as shown by the following analysis:

	Railroad Quarry.	Keyes Quarry.
Lime carbonate.....	93.89	98.94
Magnesium carbonate.....	1.32	0.68
Silica	1.85	0.49
Iron and alumina.....	1.45	0.40

Greenbrier Limestone.

The Shenandoah limestone on account of its industrial development, is the most valuable limestone in the State when its present money value is considered, but the greatest limestone in the State in area and quantity is the Greenbrier or Big Limestone, No. XI. of the Rogers' series. It enters the State at the north from Pennsylvania into Monongalia and Preston counties with a thickness of 80 to 100 feet and extends southwest in narrow belts through Tucker, Grant, and Randolph counties, widening out into a broad belt across Pocahontas, Greenbrier, Summers and Mercer counties, where its thickness reaches 1,000 to 1,500 feet. It thus extends entirely across the State from northeast to southwest.

This limestone area is crossed by the Baltimore & Ohio railroad at the north and by the Chesapeake & Ohio at the south, while the Greenbrier division of the C. & O. follows the Greenbrier river north, not very far distant from the eastern outcrop of the limestone. The West Virginia Central reaches the northern outcrops at a number of points, and the Morgantown and Kingwood railroad passes across the outcrops in Monongalia and Preston counties. The limestone is thus accessible to the railroad in many places.

The physical character of the limestone varies in the same area, the limestone varying in color from nearly white to a dark blue, and from very hard crystalline rock to soft stone. Near Lewisburg in Greenbrier county, and Fort Spring, in the southern part of the same county, a bed of cream white limestone is filled with small spherical particles about the size of a pin head forming an oolite, the grains being carbonate of lime.

The limestone in a number of localities, especially near Hendricks in Tucker county, near Marlinton, Pocahontas county, and in Greenbrier county, contains underground water channels and caves. At the Big Springs near Marlinton there are strong streams flowing out which furnish water power for two small mills. Plate XXII. shows the stream from one of these springs, which farther on was formerly used for a grist mill. The Big Cave near these springs has been followed for several hundred feet and is high enough to walk in. A stream of water flows through a branch of this cave and the falling water can be plainly heard at the mouth though no one has yet reached the place where the stream is flowing. Numerous sink holes are found where the strata have settled through underground solution. Springs are numerous and furnish a supply of clear cold water. The overlying soils are fertile and furnish fine grazing and cultivated farm lands.

The Greenbrier limestone has become of economic importance at a number of places, but the great mass of it is not used at the present time. At the north in Monongalia county its outcrop is found on Deckers creek about nine miles from Morgantown, and can be followed up the creek for three and one-half miles. Another larger outcrop is found to the northeast on Cheat river, and the two outcrops are probably connected though in the area between, the limestone is buried under coal measure sediments and is disclosed at the two places by the stream erosion. On Deckers creek the rock was burned for lime seventy-five years ago, but at the present time is only worked at one point, Sturgisson, on the Morgantown & Kingwood railroad, where the Deckers Creek Stone & Sand Company has opened a small quarry for ballast, with a 45-foot face. The rock is blue in color and about five car loads of crushed rock are shipped daily, which is used on the railroad and for concrete work at Morgantown. Recent examinations made by the Survey show that this rock is suitable for Portland cement manufacture and considerable interest is now being taken in the cement development of this area.

Near Rowlesburg, on Cheat river in Preston county, and on the line of the Morgantown & Kingwood railroad is the plant of the Buckhorn Portland Cement Company which uses the Greenbrier limestone.

Further south in Tucker county near Hendricks, the West Virginia Lime & Cement Company built two patent draw kilns each with 350 bushels of lime daily capacity. They made a good quality of lime until the plant was closed by a law suit, and the case is still pending. This plant will without doubt be opened again as there is a large demand for lime in this section by the paper mills and tanneries. The limestone is described under the section on cements (Part III).

The only other section where the Greenbrier limestone is now used is near Fort Spring in the southern part of Greenbrier county on the Chesapeake & Ohio railroad, though a small quarry is used at Lewisburg for building stone. At Fort Spring two small quarries were opened twenty years ago and worked to about 1896 for lime and furnace flux. Two miles west of this place at a station called Snowflake, D. Y. Huddleston has a quarry in the Greenbrier limestone which he uses to supply a draw kiln holding 100 bushels and makes 50 bushels of lime a day, using wood and coal fuel. This plant is illustrated in plate XXIII. The lime is white in color and while the business is small, it has proved very successful.

One mile further west near a station called Frazier is a large railroad quarry where the rock is crushed for ballast in a No. 7 Gates crusher with a daily capacity of 500 cubic yards. The average daily output is 300 to 400 cubic yards or 10 to 12 cars. The quarry face is 125 feet high, showing about 15 feet of blue limestone at the top, then 10 to 15 feet of white oolitic limestone and 80 to 90 feet of hard blue limestone which breaks in irregular pieces under the sledge. The cover of soil and clay is about two feet, and in part of the quarry the oolitic limestone extends to the top, replacing the upper blue layer.

The chemical composition of the Greenbrier limestone was worked out in considerable detail by Rogers and given in his report of the Geological Survey for 1839. A number of these analyses are given here, and also the analyses made by the present Survey. This limestone will prove valuable in many areas of the State at some future time and interest has already been taken in its development in the northern and central parts of the State.

The following analyses are taken from the report of Prof. W. B. Rogers in 1839:¹

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Lime carbonate.....	90.92	98.20	88.32	89.44	88.52	89.76
Magnesium carbonate...	trace	0.00	....	2.80	3.24	2.32
Alumina and iron.....	1.20	0.48	2.52	0.88	1.52	1.16
Silica	6.20	0.40	7.24	6.04	6.00	5.80
Moisture	0.44	0.24	0.72	0.84	0.72	0.92

No. 1 was the limestone near Red Sulphur Springs in Monroe county described as fine grained bluish black rock with shelly or conchoidal fracture.

No. 2. limestone near Blue Sulphur Spring, light gray color, compact texture, and beautifully oolitic.

No. 3, from east side of Laurel Hill axis, Monongalia county, used as a flux at the Greenville furnace.

No. 4, from limestone on western side of Briery axis two miles south of Kingwood, Preston county, light gray color, compact texture, and irregular fracture.

No. 5 was from front ridge of Allegheny opposite Petersburg, color light lead, fine grain, conchoidal fracture.

No. 6 was a limestone used at Jenkins' lime kiln on Cheat river below mouth of Gum Camp run, color lead gray, compact texture and irregular fracture.

The following analyses of the Greenbrier limestone have been made in the Survey laboratory:

	No. 175.	No. 176.	No. 177.	No. 180.	No. 181.	No. 182.
Lime carbonate.....	87.93	97.73	71.34	82.77	92.88	48.20
Magnesium carbonate.	4.00	1.44	8.49	11.41	2.79	27.29
Silica	4.97	0.89	15.62	4.93	3.74	12.78
Alumina	1.89	0.61	3.60	1.64	1.31	7.30
Iron oxide.....	0.93		1.53			1.98
Titanium	0.05	....	0.12	....	....	0.16

	No. 183.	No. 96.	No. 101.	No. 118.	No. 116.	No. 117.
Lime carbonate.....	83.51	84.38	92.48	94.98	78.28	86.84
Magnesium carbonate.	10.56	2.36	2.46	1.38	1.51	2.11
Silica	4.61	8.90	3.52	3.31	12.64	8.28
Alumina	1.44	2.43	1.19	0.75	4.61	2.26
Iron oxide.....			0.75	1.03	2.16	1.00
Titanium .....	....	0.14	0.04	0.04	0.15	0.12

No. 175 is the blue limestone below the oolite in the railroad quarry at Frazier in the southern part of Greenbrier county.

No. 176 is the oolite in the same quarry which is ten feet thick and of beautiful structure. This may be compared with No. 2 of Rogers' analyses.

No. 177 is the so-called Pocahontas marble from the top of the mountain two miles west of Marlinton, Pocahontas county.

No. 180 is the limestone just below the marble.

No. 181 is from a small quarry on top of the hill back of Lewisburg, county seat of Greenbrier county.

No. 182 is the limestone at the Big Spring cave three miles west of Marlinton.

1. Reprinted in *Geology of the Virginias*, p. 396; 1884.

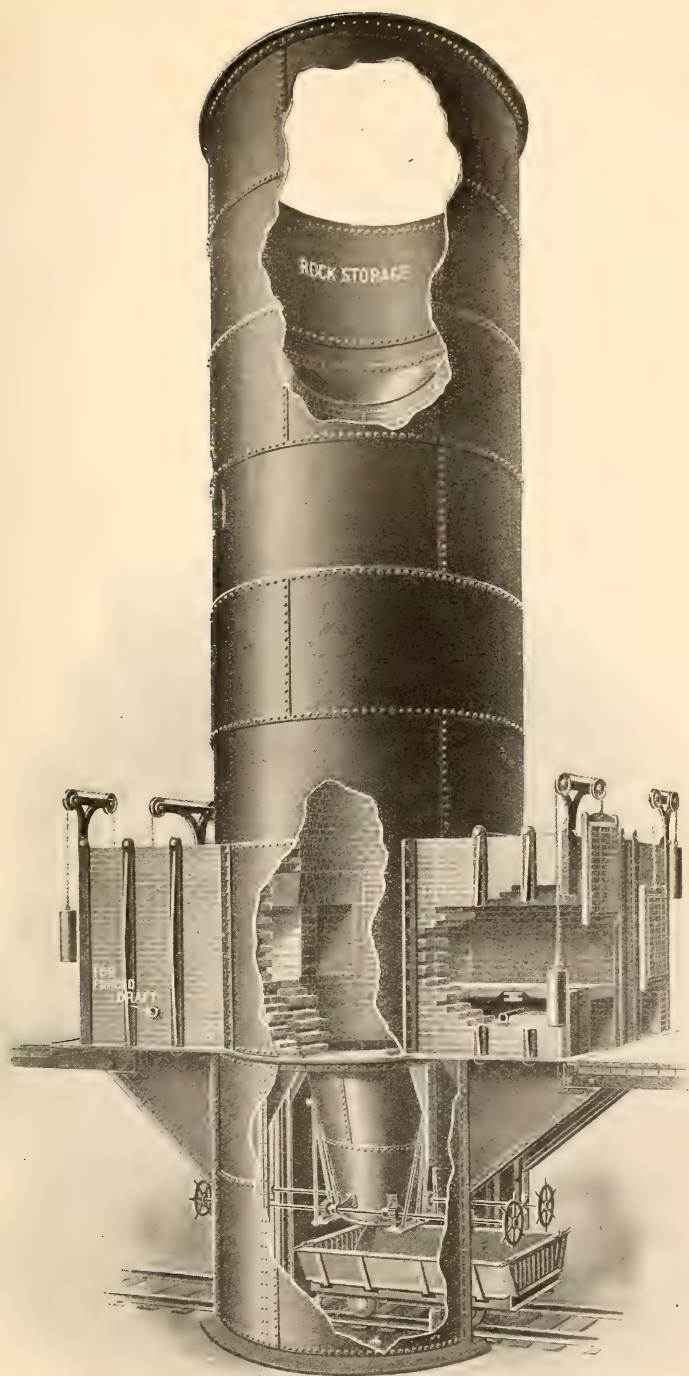


Plate XXIV.—Broomell Patent Lime Kiln—Sectional View.

No. 183 is about 50 feet from the bottom of the limestone outcrop just west of Marlinton.

No. 96 is from the northern part of the State on Cheat river in Monongalia county.

No. 101 is from same locality but 40 or 50 feet lower.

No. 118 is from Lick Run, twelve miles up Deckers creek from Morgantown.

No. 116 is from same locality and about fifteen or twenty feet higher.

No. 117 is from same locality, and about half way in vertical distance between the last two ledges.

Other analyses of the Greenbrier limestone are given as below :

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Lime carbonate.....	81.27	60.41	92.53	89.16	38.83
Magnesium carbonate.....	0.68	trace	2.15	1.93	16.30
Alumina and iron.....	6.00	9.66	0.58	2.43	6.33
Silica	12.10	24.10	4.74	6.86	36.60

No. 1 is the top layer used at the Buckhorn Portland cement mill on Cheat river near Rowlesburg, in Preston county.

No. 2 is the bottom layer, twenty feet lower.

No. 3 is the lower ledge at Hendricks, Tucker county.

No. 4 is the upper ledge at same place and forty feet higher.

No. 5 is the natural cement rock at Hendricks, one hundred feet above the other ledges.

A comparative study of these various analyses shows a general uniformity of composition across the State. Belts of magnesian limestone come in near Marlinton (No. 182) and at Hendricks (No. 5). A detailed study of the area would probably reveal other examples of this rock. The limestone near Marlinton appears to be high in magnesia at several places. Most of these analyses show rock suitable for Portland cement manufacture. Very pure outcrops of limestone are found near Fort Spring at the south and on Deckers creek at the north. It is not often that one finds such a large extent of limestone, probably 200 miles in length, with such uniform chemical composition. A cement mill could be started at almost any place in the area as far as the limestone is concerned, and shales or clays are found in nearly all parts of the area. As has been described above many parts of the area are accessible to railroads, and fuel is to be obtained at no great distance away, so that the question of markets would be the important question to be settled for proper location. The rock has been burned into good lime in the southern, central, and northern parts of the area.

The oolitic limestone at the south contains 97.7 per cent. of lime carbonate and is burned into lime at Snowflake near Fort

Spring. It can be traced for a considerable distance with a thickness of ten to twelve feet and might be adapted to ornamental building work. The Bedford, Indiana, oolite is a famous building stone over the whole country and is shipped into the eastern markets. If the physical structure of the Greenbrier oolite is adapted to such work it would prove far more valuable for this use than in making lime.

The analysis No. 177 is of a very hard, often banded rock, brown in color, found near the top of the mountain west of Marlinton, and locally called marble. The rock takes a good polish and might be used as an ornamental stone. It does not appear to be crystalline and is not a true marble. This so-called Pocahontas marble has attracted attention from an early day and a few years ago a company was organized to develop it at a point a few miles south of Marlinton near Academy. It is said to be 40 feet thick at that place. According to an expert report of Geo. C. Underhill of Vermont, made for a local company some years back, this marble is to be compared with the Tennessee and Swanton, Vermont, marble, and he gives a most favorable report on this deposit.

COAL MEASURE LIMESTONES.

The various limestones of the Coal Measures in the State will now be described, and in this section data have been freely taken from Dr. I. C. White's report on coals forming volume II. of this series.

Kanawha Series.

In the southern part of the State where the Kanawha Series is found in its typical development, the rocks are mainly shales, sandstones, coals and some limestones.

Two Mile Limestone.—In the vicinity of Charleston in the tops of the hills to the east is the Two Mile limestone with fresh water shells and named by Dr. White from its occurrence on Two Mile creek, where it is 350 feet below the Pittsburg coal. It is found at the head of Coal branch run, a tributary of Elk river near Charleston, and also at the head of Porter's run on the south side of the Kanawha above Charleston, where it is 400 feet above the Kanawha black flint, with 35 feet or more of red shales below and 20 feet of sandstone above separated from the limestone by

10 feet of shales. This limestone was at one time quarried on the farm of Capt. Swan on Porter's run and burned into lime. The quarry is now concealed by debris but Dr. White gives the following section measured when the quarry was open:

	Feet.	Inches.
Limestone	1	8
Gray shales.....	6	0
Limestone	1	4

The limestone from the upper ledge has been analyzed by the Survey and shows the following composition:

Lime carbonate.....	86.49
Magnesium carbonate.....	1.31
Alumina	3.15
Silica	7.71
Iron oxide.....	1.32
Titanium	0.09

The rock in its chemical composition would be adapted to cement manufacture, but its small thickness renders it of practically no economic value.

Campbells Creek Limestone.—Dr. I. C. White gives the following description of this limestone (Vol. II., p. 566):

The interval between the Cedar Grove coal and the Campbells Creek consists largely of alternating shales and sandstones, sometimes containing thin seams of coal, and often a peculiar earthy limestone, the whole varying in thickness from fifty to over one hundred feet. The limestone was first observed by the writer near the mouth of Campbells creek, and was named from that locality where it occurs at an interval of thirty-four feet above the coal of the same name. It frequently takes the form of lens-shaped concretions, and often exhibits the "cone in cone" structure, which is itself of concretionary origin. This limestone horizon is rather persistent in the Kanawha valley, though the stratum is seldom more than a foot in thickness.

Cannelton or Stockton Limestone.—Dr. I. C. White gives the following description of this limestone in volume II., page 586:

The interval between the Campbells creek coal and the Eagle coal is occupied by sandstones and shales, and a thin bed of impure limestone which appears to be quite persistent in the Kanawha valley. It was once manufactured into cement at Cannelton, Fayette county by Mr. Stockton, and hence it is often termed locally the "Stockton" cement bed. It is usually quite siliceous, frequently exhibits the "cone in cone" structure, and is non-fossiliferous, so far as the writer knows. Its usual place is seventy-five to one hundred feet below the Campbells creek coal, and forty-five to fifty feet above the Eagle seam. If the Eagle coal represents the Clarion bed of the Allegheny series, then the Cannelton limestone would correspond to the Ferriferous limestone of western Pennsylvania.

The limestone is from two to two and one-half feet in thickness with fine shales above and below. The rock is blue in color

and breaks with irregular fracture. An analysis was made of this rock below the station of Cannelton on the Kanawha & Michigan railroad and gave:

Lime carbonate.....	58.68
Magnesium carbonate.....	2.82
Silica	21.44
Alumina	8.60
Iron oxide.....	5.05
Titanium	0.55

The composition is very close to that of the Lehigh valley cement rock, and with its low magnesia percentage could be used with the high grade rock in the Greenbrier limestone area farther east, but the small thickness of the formation renders it valueless.

Eagle Limestone (Black Marble.)—The following description of the Eagle limestone is given by Dr. I. C. White in volume II., page 593:

A very interesting bed of fossiliferous impure "cone in cone" limestone occurs at an interval of seventy-five feet below the Eagle coal at Eagle, Fayette county, and the bed has been named from that locality. The local name for the rock is "Black Marble" since it has a very dark color and as it often occurs in the midst of bituminous slates, its mottled "cone in cone" structure in contrast with the latter has suggested this name. The limestone itself contains marine fossils and the enclosing shales are crowded with them, all of the common Coal Measures type so far as a cursory examination could determine. This limestone and its enclosing shales occur on Twenty Mile creek and along Gauley river at some localities, but outside of these points, the writer has not recognized this horizon, so that the deposit is probably confined to the Kanawha region.

Allegheny Series.

Ferriferous Limestone.—The lowest limestone in the Allegheny Series is the Ferriferous or Vanport, and according to Dr. White¹ does not appear anywhere within the boundary of West Virginia so far as known, except in Hancock county, where it is thin and impure, and underlies the Lower Kittanning coal by an interval of sixty feet, the most of which is sandy shales and shaly sandstone. Where this horizon is exposed at Valley Falls and Hammond in Taylor and Marion counties, some iron ore is present, but no limestone, and the same is true of the exposure in Preston and elsewhere in the northern portion of the State.

This limestone in western Pennsylvania reaches 22 feet in thickness and is stated by F. G. Clapp to be the most widespread and available limestone for Portland cement manufacture in west-

1. Vol. II., p. 493.

ern Pennsylvania, and is used at the Newcastle Portland cement mill.

Upper Freeport Limestone.—The only other limestone that reaches any thickness is the Upper Freeport. The Lower Freeport and Johnstown cement limestone of Pennsylvania are thin and poorly developed.

Dr. I. C. White in volume II. (page 462) gives the following account of the Upper Freeport limestone in this State:

Lying at an interval of five to twenty feet under the Upper Freeport coal, there occurs in Preston and eastern Monongalia counties, a limestone of wide distribution in Pennsylvania, but so far as observed in West Virginia, with the exception of Hancock county at the north, is confined to the two counties mentioned. It has been quarried by the farmers at many localities in Preston and burned into lime for agricultural purposes. It is usually found in several layers, separated by shales, the whole having a thickness of ten to fifteen feet. It is a fresh or brackish water deposit, no marine fossils having been seen in it either in West Virginia or Pennsylvania.

The uppermost layers of the limestone are sometimes changed to carbonate of iron, as on Deckers creek, near Dellslow, where some iron ore was once mined and used in the old furnace there. The lower part of this ledge has the following composition:

Lime carbonate.....	88.21
Magnesium carbonate.....	3.05
Silica	3.80
Alumina	1.67
Ferric iron.....	3.30
Titanium	0.08

The following analyses of this limestone in Westmoreland, Pa., are quoted by Clapp:¹

Lime carbonate.....	94.64	91.98
Magnesium carbonate.....	1.14	1.66
Silica	0.99	4.01
Alumina and iron.....	2.72	1.52

Conemaugh Series.

Mahoning Limestone.—Near the base of the Conemaugh Series between the Upper and Lower Mahoning sandstones, a limestone is sometimes present. According to Dr. I. C. White (volume II., page 323).

This stratum occurs in the vicinity of Irondale furnace, Preston county, and is there four to six feet thick and of a buff or yellowish

1. Bull. U. S. G. S., No. 249, p. 13.

hue. No marine fossils have been seen in the rock, and it is evidently a fresh or brackish water deposit.

It is also present about twenty feet above the Upper Freeport coal at the Meriden mines below Philippi, where it is exposed in a cutting along the B. & O. railroad.

It is possibly this limestone which has been mined for agricultural purposes in the hills sixty to seventy feet above the level of Sandy creek, near Bruceton, Preston county.

In the southwestern portion of the State limestone is very rare at this horizon, but near Ceredo, Wayne county, some nuggets of limestone may be seen just under the Upper Mahoning sandstone in the cuts of the N. & W. railroad.

Lower Cambridge Limestone.—Dr. White gives the following discussion of this limestone in volume II. (page 276) :

In Allegheny, Butler, and Beaver counties of Pennsylvania, there frequently occurs a dark very fossiliferous limestone over some black shales in the roof of a rather persistent coal bed. Its geological horizon varies between 60 and 95 feet under the Upper Cambridge limestone, and 180 to 200 feet below the Ames or Crinoidal bed, and was described as the Brush Creek limestone in the early reports of the Pennsylvania survey.

This Lower Cambridge limestone is seldom exposed at the surface in West Virginia, since its horizon is often concealed by the debris from the massive Buffalo sandstone above.

Dr. White found this limestone near the mouth of Cutrights run, four miles above Buckhannon, Upshur county, 160 feet above the Upper Freeport coal; on Twelve Poie river, Wayne county, three miles above Ceredo station on the N. & W. railroad, and high up in the hills at New Cumberland, Hancock county, 120 feet above the Upper Freeport coal horizon, where it is present in form of limy, fossiliferous shales. The thickness of the limestone is seldom over one foot and it is often represented merely by nuggets or nodules in the shales.

Upper Cambridge Limestone.—This fossiliferous limestone is found 90 to 120 feet below the Ames and 60 to 100 feet above the Lower Cambridge. It is found in Brooke, Hancock, and Monongalia counties, and usually contains numerous fossils of marine type. Its thickness is small, one to three feet. An analysis of the limestone near Morgantown shows the following percentages :

	Upper Cambridge.	Lower Cambridge.
Lime carbonate.....	56.48	54.76
Magnesium carbonate.....	2.37	2.66
Silica and insoluble matter.....	34.18	26.90
Alumina	3.45	8.67
Iron oxide.....	2.64	5.28

Ames or Crinoidal Limestone.—Dr. White in volume II. (page 256) gives the following description of the Ames limestone :

We come now to one of the most interesting deposits, from a geological standpoint, in the entire Appalachian field, the Green Fossiliferous limestone of the First Geological Survey of Pennsylvania, the Crinoidal limestone of Stevenson, and the Ames limestone of Andrews and Orton in the Ohio Geological Survey reports.

This stratum and its overlying limy shales are the first beds found in descending the column of rocks through the carboniferous beds that contain clearly marked marine fossils. Dr. Stevenson thus aptly describes its main characteristics:

"Dark bluish or greenish gray, tough, and breaks with a granular surface much resembling that of a coarse sandstone. * * * In all cases it is fossiliferous, and contains immense numbers of crinoidal stems and spines or plates."

The Ames limestone is seldom more than one or two feet thick, and often is represented simply by a row of limestone nuggets imbedded in fossiliferous shale. In the northern Panhandle, however, the limestone has a thickness of 10 feet. This stratum and its accompanying fossiliferous beds are exposed in the vicinity of Morgantown, also near Fairmont, and Grafton. It is conspicuous at many places in Harrison and Lewis counties. It is seen along the anticline at Burning Springs, Volcano, etc., but goes under the Ohio river southwest from Eureka, appearing again at Huntington, 150 miles below.

The Ames limestone in this State reaches its greatest thickness in the northern Panhandle, ten feet. The rock from a point north of New Cumberland and two and one-half miles southeast of Congo shows the following composition :

Lime carbonate.....	83.98
Magnesium carbonate.....	2.13
Silica	8.94
Alumina	2.41
Iron oxide.....	0.79

This limestone comes about 250 feet below the Pittsburg coal in the northern part of the State, and 100 to 125 feet above the Upper Cambridge lime. It has not been of any economic importance and probably never will be on account of its variable thickness, and where it reaches a maximum thickness it soon passes under heavy cover.

Elk Lick Limestone.—According to Dr. I. C. White in volume II. (page 254) :

This limestone (Elk Lick) is of common occurrence in Monongalia, Marion, Taylor, Barbour, and Lewis counties, at a few feet below the Elk Lick coal.

The stratum is frequently ten to fifteen feet thick in several layers separated by shales. The limestone is of fresh or brackish water origin like all of those in the series above it, but some of the layers

are fairly pure, and burn into a good quality of lime for building or fertilizing purposes. * * * * * The limestone is usually gray in color and resembles the Clarksburg limestone, sixty to eighty feet higher, so closely in physical aspect, that it has probably been frequently confused with the latter.

The Elk Lick limestone east of Morgantown has the following composition:

Lime carbonate.....	66.74
Magnesium carbonate.....	7.13
Silica	16.08
Alumina	6.56
Ferric iron.....	3.41
Titanium	0.19

Clarksburg Limestone.—On page 249 of volume II., Dr. White describes this limestone:

Directly below the Little Clarksburg coal and its underlying fossiliferous black slate, there often occurs a limestone which is finely exposed in the vicinity of Clarksburg along Elk creek at its junction with the West Fork river, and was named by the writer from that locality, the Clarksburg limestone. Its upper portion is generally rather slaty and filled with fossil ostracoids and fish remains, but the lower layers are compact and massive. The whole stratum is often twenty to thirty feet thick and some of the layers are quite ferruginous, so much so that they were once mined as ore and used in the manufacture of iron at an old charcoal furnace on Elk, near Clarksburg.

The Clarksburg limestone has a wide distribution in the northern end of the State, and has frequently been quarried and burned into lime for fertilizing purposes. It also makes excellent road material and has been extensively used for that purpose on the streets and roadways in the vicinity of Clarksburg.

An analysis was made of this limestone from near Clarksburg and showed the following composition:

Lime carbonate.....	56.54
Magnesium carbonate.....	12.31
Silica	17.18
Iron oxide.....	4.94
Alumina	7.06
Sulphur	0.66
Titanium	0.19

Pittsburg Limestones.—The Upper Pittsburg limestone is five to six feet thick and comes about thirty feet below the Pittsburg coal. The Lower Pittsburg lime comes fifty to sixty feet lower and reaches ten feet in thickness.

The lower limestone north of Morgantown on the Monongahela river is four to six feet in thickness with two shale partings. It is dark blue in color with smooth fracture and becomes nodular in its upper portion. Three analyses were made of this rock, one

from the upper portion, one from the middle, and the other from the lower part, which showed a high percentage of iron.

				Jimtown	
	Upper.	Middle.	Lower.	Upper.	Lower.
Lime carbonate.....	86.06	82.14	51.70	87.70	86.84
Magnesium carbonate.....	1.99	4.26	25.89	2.56	2.01
Silica	3.28	7.24	10.72	4.16	6.92
Alumina	3.31	4.22	13.31	2.80	1.93
Iron oxide.....	1.26	1.26		1.98	2.31
Titanium	0.05	0.08	0.19	0.04	trace

These limestone ledges were opened with a view of burning into lime, but the total thickness of the good rock would be three feet and would not be profitable at this point. It is claimed that in well borings near Randall and near the locality where the above samples were taken, the limestone was more solid and showed a much greater thickness.

Monongahela Series.

Redstone Limestone.—This limestone is found from ten to thirty feet above the Pittsburg coal and just below the Redstone coal. It varies in thickness from four or five feet to twenty feet. It is well developed near Wheeling and on Scotts run below Morgantown. Near Clarksburg and between Clarksburg and Fairmont, the limestone is nodular mixed with shales and clay. When it takes the irregular nodular form it is apt to contain a large amount of pyrite in bright crystals well seen in the shale pit of the High Grade Shale Brick Company at Clarksburg.

Near Wheeling the rock is light gray to bluish in color and very brittle. It is quarried in small openings along streams for use on the roads. Many of the Ohio county roads from Wheeling east are macadamized with the Redstone limestone. The great fault of the rock for this purpose is its brittle character, which causes it to break up into fine fragments, but it is a better road material than the Uniontown limestone, also used to a large extent in this section.

On Scott's run there is an extensive outcrop of the limestone which is about eighteen feet thick, and while no use has been made of the rock, it is adapted to cement manufacture, as will be more fully discussed in chapter XXI. of Part III. of this report. The following analyses will show the composition of the rock on Scott's run and near Wheeling:

	Scotts run.	Wheeling.
Lime carbonate.....	79.63	76.86
Magnesium carbonate.....	1.44	5.22
Silica	12.21	11.87
Alumina	2.87	4.68
Iron oxide.....	2.36	1.97
Titanium	0.15	0.09

Sewickley Limestone.—The Sewickley coal is found fifty to seventy feet above the Redstone limestone and below the coal is the Sewickley limestone, varying in thickness from a few feet to twenty-five feet. In the vicinity of Wheeling this limestone comes down almost to the Redstone coal, which is thin with Redstone limestone under it, making a heavy body of limestone over the Pittsburg coal.

The analysis below was made from a sample of the limestone above the Redstone coal on Scott's run and shows a fairly pure rock except that it is rather high in silica. The other analysis was made of the average of 28 feet of Sewickley limestone opposite Carter run east of Wheeling.

	Scotts run.	Wheeling.
Lime carbonate.....	83.52	74.58
Magnesium carbonate.....	3.78	10.63
Silica	10.54	9.96
Alumina	0.75	3.28
Iron oxide.....	2.06	1.54
Titanium	0.05	0.10

Uniontown or Great Limestone.—This limestone consists of a series of limestone layers separated by limy shales reaching a total thickness of 100 feet or more. It is well developed through the western part of Monongalia county and especially in Ohio county. Near Wheeling and east for eight miles along the creek valleys the limestone forms vertical banks forty to sixty feet in height. The rock breaks readily and weathers into small angular fragments. The color varies from white to a gray and blue. The shaly layers separate the more solid strata and by weathering give an irregular cliff with the harder layers projecting. The physical appearance of this rock is so characteristic in this section that the Uniontown limestone is readily recognized in passing through the country.

The purer layers were quarried at one time for use as flux, but at the present time its only use is for road material. A blow of the hammer shatters the rock into numerous fragments and its life as good road material is short, but its abundance and

ease of breaking into a coarse gravel make it cheap, and it is used on the National road and other county roads. No county in the State outside of the eastern Panhandle has as good roads as Ohio.

On Scott's run near Morgantown, the Uniontown limestone consists of ledges six inches to two feet separated by shales. Some of these layers are highly magnesian and are locally known as cement beds. When traced southwestward the limestone layers disappear and are replaced according to Dr. White by red shales and sandy beds, so that near the Little Kanawha river only a few thin layers of impure limestone can be found.

The following analyses of this limestone have been made:

	Scotts run	Wheeling average.
Lime carbonate.....	86.70	47.34
Magnesium carbonate.....	5.32	17.69
Silica	5.96	22.22
Alumina	1.01	8.57
Iron oxide.....	1.27	2.01
Titanium	0.07	0.21

The sample from Scott's run was taken near the top of the series and represents a fairly pure ledge. The Wheeling samples were taken four miles up Wheeling creek near Elm Grove.

Waynesburg Limestone.—This limestone is found twenty to thirty-five feet below the Waynesburg coal. On Scott's run, Monongalia county, it is eight feet in thickness, and in some of the deep wells reaches 24 feet. It has been burned into lime on a small scale in Pennsylvania.

Dunkard Series.

Washington Limestones.—The Lower Washington limestone according to Dr. White is generally present in Monongalia, Marion, Harrison, Wetzel, Tyler, Marshall, and Ohio counties, but disappears southwestward in Doddridge, Ritchie, and adjoining counties. It often forms with shales the roof of the Washington coal, and its average thickness is about five feet.

The Middle Washington limestone is not a persistent bed in West Virginia, and comes about 140 feet above the Lower limestone, and is two or three feet thick. The Upper Washington limestone is 90 to 100 feet higher and only a short distance below the Jollytown coal, and is four to five feet in thickness. The

Lower Washington limestone has been quarried for road material between Elm Grove and Wheeling and it might be burned for lime, but the thickness is small. The other two limestones have not been quarried in any of the areas visited.

Nineveh Limestone.—Dr. I. C. White gives the following description of the Nineveh limestone in volume II. (page 109) :

Below the Nineveh coal at an interval of 25 to 30 feet, there is found a limestone that appears to have a very wide distribution. It usually occurs in several layers, and these may be separated by marly or sometimes bituminous shale, the whole often twenty or more feet in thickness. Some of the layers of limestone are of fair quality while others are quite impure. The outcrop of this limestone is finely shown at either portal of Board Tree tunnel, on the Marshall-Wetzel county line; also at the foot of the hill on the road between Maple and St. Cloud, Monongalia county. Its crop may be seen along the public road leading from St. Cloud to Hundred, one-fourth mile east of the Winona-Shough oil well and 70 feet above the derrick floor, thus making its position there 960 feet above the Pittsburg coal, since the latter was found at a depth of 890 feet.

It appears to be this same Nineveh limestone that crops through Wood, Wirt, and Jackson counties, extending nearly through to the Big Kanawha river, and occurring well up in the summits of the hills. It is known south of the Little Kanawha river as the "Ridge" limestone from its occurrence along the ridges, and it adds much to the fertility of the soil. It gives name to Limestone Hill P. O., on the Parkersburg and Charleston turnpike, near the corner of Wirt, Wood, and Jackson counties, where it crops on the summit and appears to be nearly 30 feet thick.

At Bellton or Denver station on the Baltimore & Ohio railroad the Nineveh limestone is found in the hills, over 200 feet above the railroad. The rock is separated into two or three ledges separated by shales with a total thickness of ten feet. The limestone ledges are one to two feet thick. The upper ledge has the following composition :

Lime carbonate	73.28
Magnesium carbonate.....	1.88
Silica	16.18
Alumina	0.70
Iron oxide.....	2.64
Titanium	0.22

Windy Gap Limestone.—This is the highest limestone of the Dunkard series in this State and therefore the highest limestone in the geological series. It is sparingly fossiliferous with fresh water shells. In color the rock is blue, weathering to a gray or even buff and has a thickness of five to eight or ten feet. The outcrop is found in the high hills of Marshall, Wetzel,

western Marion, and Monongalia counties. An analysis was made of the Windy Gap limestone from the top of the hills near Bellton (Denver) :

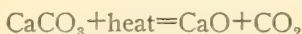
Lime carbonate.....	89.78
Magnesium carbonate.....	1.43
Silica	5.51
Alumina	0.81
Iron oxide.....	2.74
Titanium	0.05

The limestone is quite pure, nearly 90 per cent. lime carbonate, but its thickness is small.

CHAPTER XV.

TECHNOLOGY OF LIME MANUFACTURE.

When limestone, marl, chalk, or shells, composed essentially of carbonate of lime (CaCO_3) are heated in a current of air at a temperature of 850 to 1,000 degrees C. ($1,562^\circ$ to $1,800^\circ$ F.), the carbonic dioxide (CO_2) is driven off leaving a lime oxide (CaO) known as quick lime. This reaction is represented by the formula.



The amount of heat required to produce this change is stated by Gruner¹ to be 373.5 calories for one kilogram of lime carbonate. Changing this figure to the English equivalent which is more commonly used in this country, one pound of lime carbonate would require 747 B. T. U. (British Thermal Units).² Eckel³ gives the heat requirement as 784 B. T. U. According to the Gruner figure one ton of pure lime carbonate would require 1,494,000 B. T. U. to remove the carbonic dioxide, or according to the Eckel figure, would require 1,568,000 B. T. U. The carbonic dioxide does not begin to pass off until a temperature of over 800° C. (1472° F.) is reached, which would require for one pound of lime carbonate 272.8 B. T. U., or for one ton, 545,600 B. T. U. according to Eckel, whose table is quoted below giving the heat requirements for these changes in pure limestones and dolomites as well as the theoretical amounts of fuel required:

1. Polytech. Jour. CCIV., p. 39, quoted Min. Indus. VII., p. 484.

2. British Thermal Units represent the number of pounds of water which one pound of fuel will raise 1° Fahrenheit, while using the metric system one calorie represents the number of kilograms of water, one kilogram of fuel will raise 1° Centigrade. One calorie equals 4 B. T. U.

3. Cements, Limes, and Plasters, p. 98; 1905.

**For One Ton of
Limestone.**

Composition of Limestone.

	100% CaCO ₃	80% CaCO ₃ 20% MgCO ₃	50% CaCO ₃ 50% MgCO ₃
Heat required for heating to dissocia- tion point..	545,600 B. T. U.	457,600 B. T. U.	369,600 B. T. U.
Heat required for actual dissocia- tion	1,568,000 "	1,406,800 "	1,165,000 "
Total heat re- quirements.	2,113,600 B. T. U.	1,864,400 B. T. U.	1,534,600 B. T. U.
Coal theoretically required. (14,000 B. T. U. per pound).			
Intermittent kilns.....	151 lbs.	133 lbs.	110 lbs.
Continuous kilns.....	112 lbs.	101 lbs.	76 lbs.

The continuous kiln shows a considerable saving in fuel requirement, and the presence of magnesium carbonate lowers the requisite fuel. In practice more fuel is required than is shown by the theoretical calculation. As shown in the table, 112 pounds of coal are required to burn a ton of pure limestone in a continuous kiln, or about 11 pounds to the barrel (200 pounds).

According to the same author, 300 to 500 pounds of coal are required in practical work to burn a ton of lime, or 30 to 50 pounds to the barrel. This would make a fuel requirement of about 187 to 312 pounds of coal for one ton of limestone, or one and two-thirds to nearly three times the theoretical figures. In the lime kilns of the eastern part of West Virginia, 500 to 600 pounds of coal are required to burn a ton of lime or 312 to 375 pounds of coal to the ton of limestone, or two and one-third times the theoretical requirement. In the presence of moisture the stone burns more readily, the escape of the carbonic dioxide apparently is aided by the presence of water vapor or steam.

A study of the above figures shows a great waste of heat in the burning of lime, which is greater in some plants than the figures quoted would indicate. Various types of kilns, fire places, and burners have been patented which claim to reduce this waste and add to the economy of lime manufacture. The cost of fuel represents one-fifth of the total cost of lime in average plants.

FUEL FOR LIME BURNING.

Wood has been the favorite fuel for burning lime from the beginning of the industry, and at the present time it is used in many lime centers even where it has to be shipped from distant points and at higher cost than other fuels. In a number of sections wood burned lime commands a higher market price than limes burned with other fuels. It is there claimed to be whiter in color, more uniformly burned and therefore stronger. In some cases these claims are well founded, and the early attempts at burning lime with coal fuel resulted in a lower grade product. With the old style lime kilns adapted to wood burning, coal can only be used successfully by mixing with wood, and this method is now used at many plants. In Ohio it requires one cord of wood to burn 50 to 80 bushels of lime from magnesian limestone. In the southern part of West Virginia near Fort Spring, a limestone containing about 97 per cent. lime carbonate is burned into lime with a mixture of wood and a small amount of coal. It requires $2\frac{1}{2}$ cords of wood to burn 50 bushels of lime or 150 bushels a day, so that one cord of wood plus a small amount of coal burns 60 bushels of lime.

Coal, as has been stated, is used in a number of lime plants to partially replace the wood, and in Ohio is said to represent a saving of nearly two cents a bushel of lime in fuel cost.

The use of coal alone in the ordinary lime kilns has not been successful without the use of special draught appliances, as the high temperature in the coal combustion is found in the fire box and the flame is not carried as far into the kiln as in the wood fire. The result was an overburning and darkening of the lime near the fire boxes, while the lime some distance away was underburned. Further, the settling of the stone in the kiln lessened the draught and it was almost impossible to keep the coal fires at their maximum efficiency. It is stated that 50 per cent. more fuel in form of coal was required than in form of wood. In the stone pot kilns where the fuel and rock were added in alternate layers, the coal fuel was successful in burning the lime but usually gave a darker lime.

With the growing scarcity of wood, and the greater advantage of coal fuel if it could be adapted to the work of lime burning, various methods were patented and used to render coal an efficient

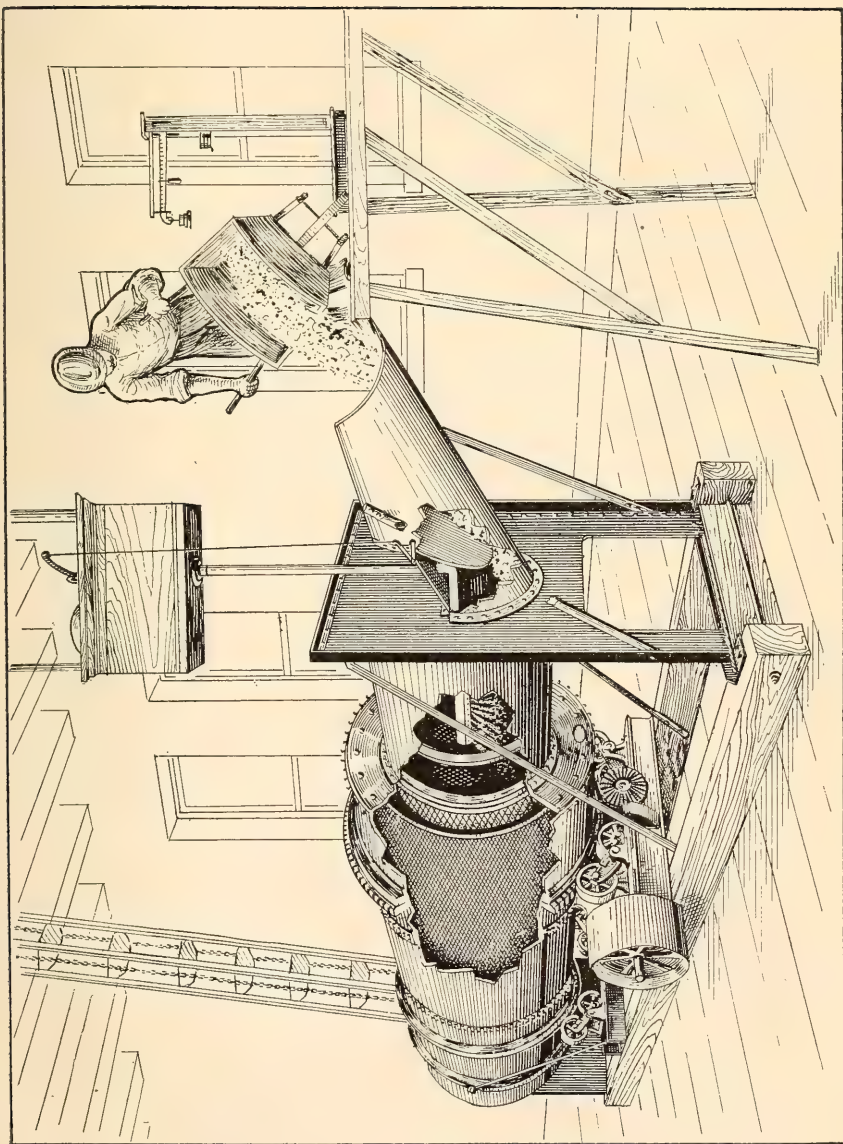


Plate XXV.—American Lime Hydrator Machine—Sectional View.

lime fuel. The basic principle of most of these methods is a reinforced or mechanical draught, of which there are two methods and four prominent types.

The two methods of securing increased draught in a kiln are the *forced* and *induced* draught. In the former, the draught is increased by forcing a current of air or steam or both through the fire boxes from below the grate bars. In the induced draft, suction is applied at or near the top of the kiln, drawing off the gases and drawing the flame up into the kiln. There is some difference of opinion as to which is the better method and both are used.

The four prominent types of draught now in use are air, steam, air and a gaseous diluent known as the Eldred process, and use of a suction fan at the top of the kiln. The first two represent a forced draught, the last a simple induced draught, while the Eldred process is a combination of induced and forced draught.

Actual trials have shown that one ton of coal will burn from three to five tons of lime, the variation being due to method of draught used. There is no question of fuel economy by the use of these added draught appliances, though it is claimed by some lime burners there is an important question of quality of lime involved. One cord of wood will burn two to three tons of lime. In an ordinary lime kiln without any artificial draught appliances, one ton of coal will burn about the same amount of lime as one cord of wood, though the heating value of the coal is much greater. The ordinary conditions of a lime kiln furnace are much more favorable for securing greater efficiency from wood fuel than from coal fuel. Economy of manufacture of lime with coal fuel now demands some form of reinforced draught and lime manufacturers are now recognizing this fact, about which there will be no question when wood fuel for lime is a thing of the past. While it is true that good lime can be made with coal fuel with reinforced draught, it is also true that the careless use of such draught will injure the quality of the lime and too strong a draught will also increase the fuel cost beyond the necessary amount.

There are two dangers to the quality of the lime by careless or wrong use of reinforced draught. First, if the heat is made too

intense, it may cause a chemical union of lime and silica impurity of the limestone which forms a lime silicate as in cement manufacture. This reaction would result in hard masses in the lime and also in the formation of a silicate coat around the blocks of limestone preventing thorough calcination of the interior with a result of under-burned cores. Second, the included moisture of the stone being suddenly changed into steam by the excessive heat would burst the blocks of stone into smaller blocks and the expansion of the rock itself would bring a similar result. Such changes would yield a lime composed of small pieces with much lime dust and would have poor keeping quality.

If hydrated lime becomes as popular as many lime men believe, and most of the lime is hydrated before going on the market, this second objection instead of being a fault would become a benefit to the manufacturer as hydration would be more rapid.

There is also a possible third objection to the use of an excessive draught, in that the increased draught would carry a portion of the ashes into the kiln there to be fused or included with the lime. If the ash is high in alkalies or the coal high in sulphur, the trouble would be increased as the lime would be more readily fused or darkened in color.

It is thus seen that the adoption of such increased draught appliances requires judgment in their use and careful trials to secure the requisite amount of draught to reach the greatest economy of fuel and best lime product. At the present time there are not sufficient data collected to compare the relative merits of forced and induced draught, and unfortunately very few data are accumulating. The lime manufacturers are too busy supplying the trade to bother with experimental work along these lines and they are very apt to be satisfied with the draught method installed without investigating the scientific problems involved. The National Lime Manufacturers' Association, organized in the last few years, through their various meetings with resulting interchange of experiences and ideas, is doing a good work along these lines and its members are paying more attention to the scientific side of lime manufacture than was possible for individual operators working on their local problems.

In the air draught, compressed air is forced through a pipe to the fire boxes of the kiln and increases the temperature by in-

suming complete combustion of the fuel, and further carries the flame and heat well up into the kiln. There is a marked saving in fuel and increase in capacity of the kiln. Against the use of a forced air draught it is claimed that the temperature is raised so high in the lower part of the kiln that the lime is burned too quickly causing the rock to break up into small lumps which on exposure to the air rapidly slake, lowering the quality of the product. It is also urged that the air blast introducing a large amount of air into the kiln, air slakes the lime. The ordinary slaking of lime on exposure to the air is due to the absorption of moisture forming a hydrate. If dry air is used in the forced draft there could be no additional slaking of the lime in the kiln through the air admitted in the blast, and even if the air was moist there would be no absorption of moisture at the high temperature of the kiln. The absorption of carbonic dioxide by the lime in air is a very slow process, accelerated by the presence of moisture, so that this change within the kiln at high temperature could not take place.

In the use of an artificial air draft with coal in burning lime there is always the temptation to increase the draught and thus increase the capacity with the resulting danger of over-burning and causing the small lumps of lime which, after leaving the kiln, slake more rapidly on account of their smaller size, giving greater surface exposure to the action of the air. In this State up to the present time, the kilns where coal fuel alone is used have an artificial air draught. In one plant there are twelve kilns, six of which use the air draught and six use a mixture of coal and wood. It is nearly impossible to see any difference in the product as drawn from the kilns. It would be of interest to know the difference in cost and daily capacity between these kilns and to test the two limes in the laboratory, but unfortunately this particular company refused to furnish any data to the Survey or permit its officers to enter their property. This is the only company in the State engaged in any line of mineral production which has ever refused to aid in every way possible the work of the State Survey.

In the use of a forced air draught it is important that the requisite amount of air should be used, an excess of supply will prove wasteful of fuel. The air should be heated, or a considerable amount of available heat of the fire will be consumed in

heating the air. The admission of cold air below the grate bars to increase the temperature of the kiln and carry the heat farther up the stack is very wasteful of fuel.

In the Shoop kiln described later the cooling lime in the lower part of the kiln gives off heat which is drawn through an opening and passes up as heated air through the grate bars, the ash pits being shut off from the outside air. A steam jet is introduced under the grate bars, thus increasing the draught while the presence of the steam tends to prevent the rapid combustion of the fuel. The objection urged against this method on the ground that the introduction of steam will tend to slake the lime is not supported, for the lime at the high kiln temperature would not absorb moisture.

The Eldred process of burning lime with coal was patented early in 1902, and has been adopted by many of the large lime companies who pronounce it a success. The object of the inventor, Byron Eldred,¹ of New York city, was to secure a long flame with coal fuel, bringing the heat of the fuel well within the kiln instead of in the fire boxes. He thus aims to regulate and control the duration of combustion by regulating the temperature and volume of the flame by means of a mixture of air and a natural gaseous diluent composed of the kiln gases drawn from the upper part of the kiln. These gases are neutral in being neither combustible nor supporters of combustion since they are poor in oxygen and can be mixed with sufficient fresh air to give the required percentage of oxygen in the mixture. The diluent gases act as a carrier of the heat of combustion, lowering the temperature of combustion but distributing this heat uniformly near the material to be heated.

The Eldred apparatus is illustrated in figure 31 applied to a common type of lime kiln: **G** is the furnace connected with the cupola of the kiln **A** by an opening or arch. **J** and **K** are the fire and ash-pit openings, provided with suitable doors. A draught pipe connects at its upper end with the kiln **A** through the opening **C**, and at its lower end with the ash-pit **B** through an opening **E**, and has in it a fan blower **D**. That part of the conduit above the fan constitutes the suction pipe of the fan and the part below is a delivery pipe from the fan. A gate or valve **H** controls the de-

1. Data furnished the writer by Mr. Eldred, and article on "Flame Regulation" by Carleton Ellis, in *Electrochemical Industry*, Dec. 1904.

livery pipe. The fan also has an auxiliary outlet I, controlled by a gate or valve through which a portion of the kiln gases may be diverted from the delivery pipe where there is an excess of the gases over the amount required for the fire. At F the suction

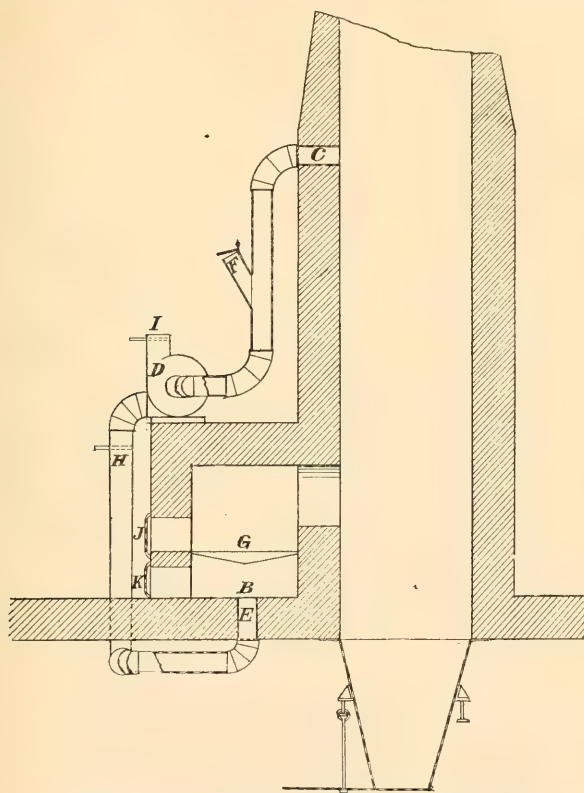


Fig. 31.—Eldred Process of Induced Draught for Lime Kilns.

pipe is provided with an air inlet controlled by a valve. By adjusting this valve the relative proportion of air and kiln gases in the draft may be exactly controlled.

Mr. Ellis in the article quoted gives the following advantages of the Eldred process as based on actual trials: One ton of coal in this process will yield about six tons of lime, and one firm reported a saving of \$50 a week per kiln by this process. The output may be increased to 50 per cent. over the ordinary kilns and gives a very uniform lime through the uniform heat dis-

tribution. There is also claimed to be a great saving in repairs of grates and furnaces.

Oil fuel has been used for burning lime where crude oil was low in price and readily obtained for use, but its use requires special construction of the kilns and the early attempts to use this fuel in the Ohio lime kilns was unsuccessful.

Natural gas has been used for burning lime in a number of states. On account of the high temperature generated near the burner, there has been considerable trouble in securing a uniform lime product, some of the rock being over-burned while in other parts of the kiln under-burned cores remained in the lumps. Where natural gas has been used in this process, meters are seldom employed, and accurate data on amount of gas required are difficult to obtain, but approximately 200 to 300 cubic feet are used in burning a bushel of lime.



Fig. 32.—Morgan Gas Producer Used With Lime Kilns.

Producer gas has been used for fuel in lime burning and two systems have attracted especial attention, the Morgan, and the Swindell. The Morgan system gas producer shown in figure 32, consists of a cylindrical steel plate shell which extends into a water-filled ash pan. The top of the producer is covered by a

shallow open cast-iron pan filled with water. Through a central opening an automatic feeding apparatus communicates with the interior of the producer. At the bottom is one central tuyere which distributes a mixture of air and steam uniformly over the interior of the producer. After the fire is started the whole operation is continuous and automatic. The coal feeder distributes the fuel evenly through a revolving delivery spout and is filled once an hour. All joints are water sealed, and ducts lead from the producer to the ash pit doors and air is admitted through the firing doors, giving combustion above the grates. The ducts are provided with doors for removal of the soot which forms a deposit of once inch in twenty-four hours.

At the lime plant at New Milford, Conn., a two weeks' run showed a saving over old methods of 40 per cent. in fuel, and an increase of 20 per cent. in capacity of the kilns. The cost was lowered from 25 cents to 17.2 cents a barrel of 300 pounds and the capacity of the two kilns equipped with this apparatus increased from 65 to 80 barrels to a kiln daily.¹

The Swindell² gas producer and burner have been successfully used by the Toledo White Lime Company. The coal is introduced into the producer through four coal hoppers which are made gas tight. The ashes are removed through water sealed boshes near the bottom and at the sides of the producer. Steam and air are introduced under and through the inclined grates by a blower through two pipes. The air for the combustion burner is pre-heated in the producer, being introduced below into a circulating chamber around the producer. The heated air and gas are conducted to the burner in separate flues and by their union in the burner give high combustion temperature.

There is claimed to result a marked increase in output over old methods, amounting to 65 per cent. according to the inventor. A cheaper quality of coal can be used and the flame is said to be clear, uniform in temperature, and can be lengthened or shortened as may be necessary. The Swindell method has also been used in cement burning with a saving in fuel and labor.

1. Rock Products, Vol. IV., No. 8, p. 41.

2. Wm. Swindell & Bros., Pittsburg, Pa.

KILNS USED IN LIME MANUFACTURE.

The primitive method of burning lime for local supply in the earlier history of the industry, and which is still occasionally used in some farming districts to secure lime for fertilizer or for plaster, consists of a heap of logs on which were placed small blocks of limestone. The fire was started and when the logs were burned the lime blocks were sorted and the under or over-burned portions thrown aside. In Ohio county, this State, some lime is made by this method at the present time. Such lime is poorly burned and does not represent a good product but serves its purpose for small uses, and has an advantage of cheapness, costing practically nothing but the trouble and labor.

Later in the history, the lime rock was piled in heaps or ditches¹ containing 1300 to 1400 cubic feet. These heaps were 10 to 14 feet high and produced about 1000 cubic feet of lime. The stone was piled upon a grate of wood, the larger pieces being placed toward the center and forming the draught channels, while toward the sides and top smaller blocks of stone were placed. The fuel was mixed with the stone and the pile covered with fine stone or clay through which passed the necessary draught holes. It required $1\frac{1}{4}$ measures by volume of coal slack to burn 6 measures of limestone.

The next improvement was the construction of a kiln with permanent side walls in the form of the old "dug out" kiln which Gilmore in 1863 describes as one of the common types in Europe and the United States, but which at the present time has practically disappeared.

According to Gilmore² the kiln was usually located on the side of a hill so that the top was accessible for charging the kiln, and the bottom for supplying the fuel and drawing the lime. The largest pieces of the stone are first selected to form the arch. Above the arch the kiln is filled by throwing the stone in loosely from the top, taking the largest pieces first and the smaller afterwards. The wood fire was started below slowly so as to gradually heat the lower stone and not crack the arch, the fires were then increased until the stone reached white heat. After burning, the kilns were allowed to slowly cool.

1. Frasch. Mineral Industry VII., p. 485.

2. Limes, Hydraulic Cements and Mortars, p. 139.

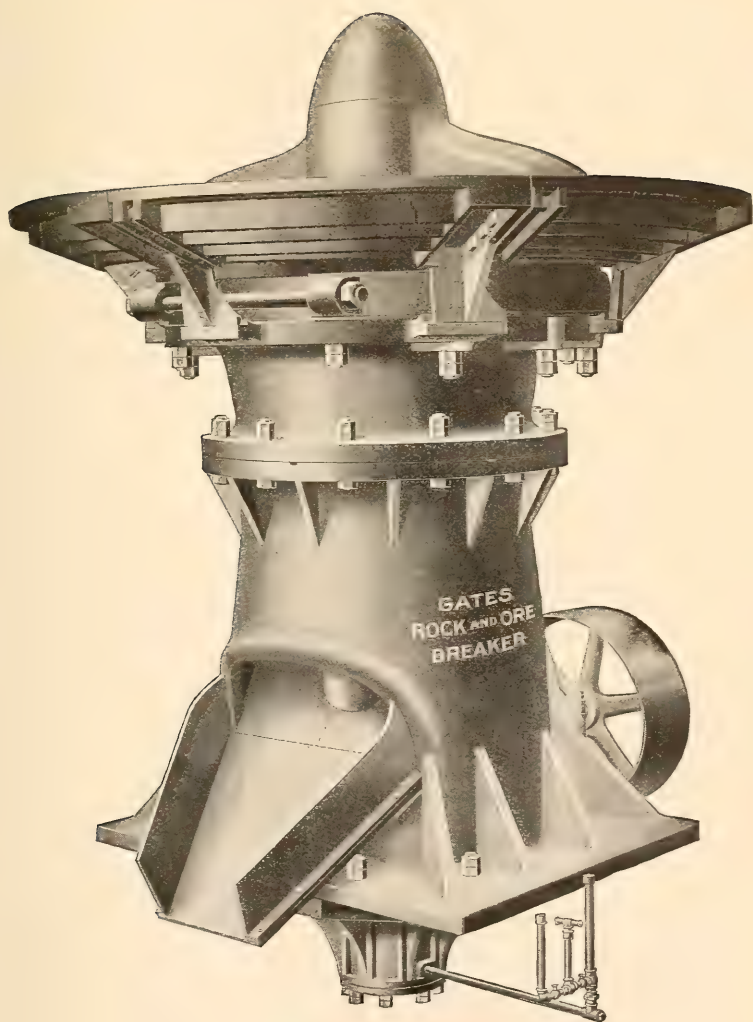


Plate XXVI.—Gates Rock Crusher.

The work of this type of kiln was intermittent and the kiln had to be cooled, and then refilled. There was a great waste of fuel in heating the cooled kiln each time it was recharged, but where the demand was small so that a kiln of lime would last some time and wood fuel was abundant, this style of kiln was successful and fulfilled its purpose perhaps better than the modern draw kilns would have done, but the time of profitable lime burning with intermittent kilns is past except in sections remote from railroads where there exists a small demand for lime and wood fuel is low in price. According to Frasch,¹ this type of kiln was fired 72 hours, cooled 12 hours, and it required two to three volumes of hard wood for each volume of lime.

In a modified type of this kiln, the square stone wall is built up above the fire box, about one-half the height of the kiln, and the remainder of the walls are composed of logs set square and plastered with mud.

Continuous Types of Lime Kilns.

In the continuous kilns the lime is withdrawn from below, while new material is added at the top, the fires are kept up constantly and there is no interruption in the work except for repairs or to decrease production.

In the old type of square stone kilns, the height is 18 to 20 feet and the sides of the square 10 to 12 feet. The coal and limestone are added in alternate layers. At the bottom is a layer of wood, which fired, starts the combustion of the lower layer of coal and the fire gradually works through the kiln, as the lower burned lime is removed, new layers of coal and limestone are added above. A few trials give the correct proportions of fuel and stone to be used. The kilns are cheap in construction, the process of burning is simple and the lime is usually of good degree of strength, but is apt to be dark in color.

The amount of fuel required² is about one volume of soft coal, one and a half of coke and three or four of lignite for three volumes of limestone. The layers of limestone are 12 to 18 inches deep, and a kiln of 1200 to 1400 cubic feet capacity will yield 700 to 900 cubic feet of lime in 24 hours. Great care is re-

1. Mineral Industry VII., p. 487.

2. Frasch. Mineral Industry VII., p. 488.

quired in drawing the lime in these kilns to secure a good product, for if drawn too soon, the lime will be under-burned, and if left in the kiln too long, the fire crowds toward the top permitting the lower part of the kiln to cool down. There is very little danger of over-burning if only enough fuel is placed in the layers to burn the lime.

In the Jefferson, Berkeley county lime district, there are twenty of these stone pot kilns, which were used in the early history of the industry for building lime, but at the present time they are used from time to time in the manufacture of agricultural lime. Each kiln has a capacity of limestone for 300 to 325 bushels of lime.

Iron or steel shell drawn kilns are now generally used in the large lime plants. Many of these are constructed after local patterns or based on the principle involved in old expired patents. The shaft of the kiln consists of an outer cylindrical shell and an inner brick cylinder composed of two or three rows of fire brick or a row of red brick with an inner lining of fire brick. Between the steel shell and the brick cylinder is packed a non-conducting material, earth or ashes. The shape of the inner cylinder, the form of grates and fire places vary in different designs of kilns.

Most of the kilns used in the eastern part of the State are built on the plan of the old Decker patent, with the interior widening at the top and tapering at the bottom. They are usually six feet in diameter and twenty to twenty-five feet high with a daily capacity of 250 to 300 bushels of lime in twenty-four hours. Below the fire places the cooling part of the kiln in some types widens to eight feet in diameter. Coal is used as fuel and is burned in three horizontal furnaces built out from the kiln at points equi-distant. In a few kilns there are only two of these furnaces.

The kiln shed has three floors, the upper near the top of the kiln for loading and connected with the quarry by inclines. The middle floor is level with the coal bins and is the firing floor, while the ground floor, about level with the floor of the freight cars, is the drawing floor where the lime is removed and packed in barrels or loaded as bulk lime.

The Standard Lime & Stone Company have 12 kilns at Bakerton, 3 kilns at Engles, 10 kilns at Martinsburg, and are planning to build six or more south of town. These make a total

of 31 kilns with a capacity of probably 6,000 bushels daily and an actual production of probably 4,000 bushels, which will be increased when the six new kilns are completed.

Keller Brothers have four iron-clad kilns at Engles with a capacity of 1200 bushels daily, and the one small kiln of the McDowell Lime Company at Martinsburg has a capacity of 160 bushels a day but is not in constant use. The new plant of the Harpers Ferry Lime Company at Millville has completed three

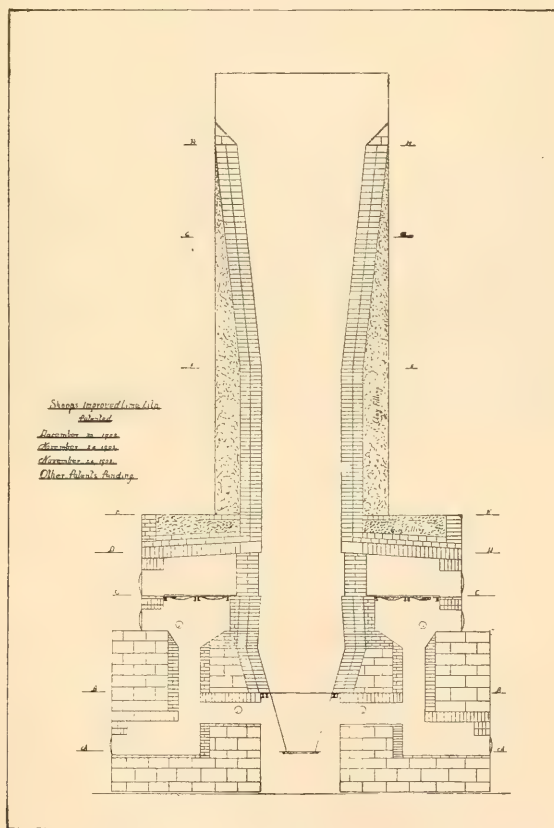


Fig. 33.—Sectional View of Shoop Lime Kiln.

Shoop kilns with a capacity of 1200 bushels of lime daily. The total capacity of the lime kilns in Berkeley and Jefferson counties is nearly 9000 bushels daily or 3000 barrels.

The only other lime kilns in the State are two Coleman iron-clad kilns at Hendricks with a daily capacity of 700 bushels, but the plant has been idle for four years on account of litigation. Also one small kiln near Fort Spring. The lime industry of West Virginia is thus confined almost entirely to the two counties of the eastern Panhandle.

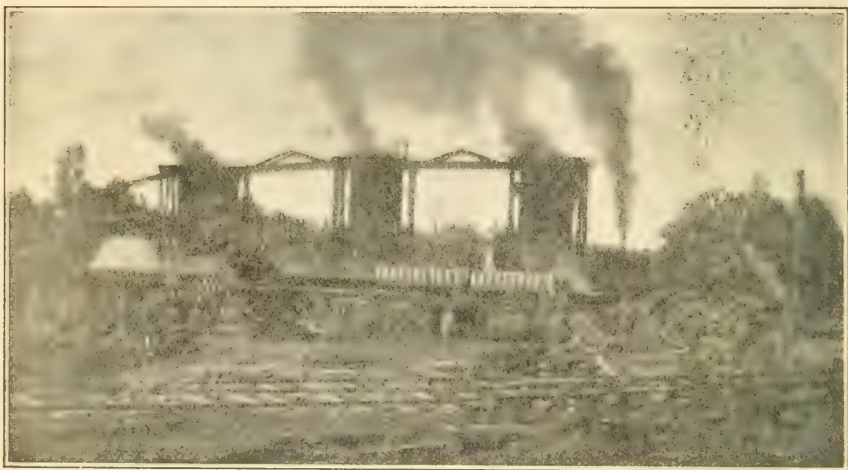


Fig. 34.—General View of Three Shoop Lime Kilns.

Shoop Kiln.—The S. W. Shoop kilns¹ recently completed at Millville, are known as center draught kilns and rest on a foundation of common brick or stone. The stack (shown in section in figure 33, and a view of the three kilns is given in figure 34) is made of 3-16 inch steel, 12 feet in diameter and 25 to 30 feet high and rests on a rock foundation. The inner cylinder is made of fire brick supported by a back wall of red brick. The inner diameter of the cupola is 5½ feet near the fire boxes and 8 feet near the top. This leaves a space of about 18 inches below, between the brick cylinder and the steel cylinder, which is filled with ashes or earth packed solid. The shape of the interior of the cupola is conical to about the middle and then becomes a cylinder. The barrel below the furnaces to the cooling pot is lined with fire brick so that the lime is partially cooled before reaching the cooler pot which is

1. S. W. Shoop & Co., Altoona, Pa.

made of one-fourth inch steel and four feet long, bolted to a base five feet square so that it may be easily repaired. The opening of this pot is closed by shears readily operated to discharge into the car below. Fire brick pillars at the furnace openings into the cupola prevent the lime dropping into the fire boxes and choking the draught.

The following explanation and claims are made by the designer of this kiln (S. W. Shoop) for the natural draught:

The kiln is constructed with two chambers or ash-pits to each side under the firing doors. One is located centrally underneath the other, with foundation on the floor line connected with flumes around the cooling formation of lime chamber, which gather the heat and hot air from the cooling lime and distribute it underneath the grate bars. The velocity that this heat gathers passing through these flumes is almost equal to forced draught, and making it the strongest natural draught kiln constructed. Not only are there advantages derived through draught, but a large saving in fuel is effected by the utilization of this hot air.

Taking into consideration that it requires about 12 pounds of air (or 50 cubic feet) to consume one pound of coal, and that this air flowing under the grate bars in the ordinary style of kiln at an average of 70 degrees F. has to be raised to a temperature of nearly 2,000 degrees F., there is economy in collecting and utilizing the waste heat from the cooling lime. By the introduction of a small jet of steam underneath the grate bars in connection with this hot air, there is an excellent force draught for coal.

Broomell Kiln.—The Keystone lime kiln made on the Broomell patents¹ is another popular steel clad kiln built on somewhat different plan from the Shoop kiln. The supporting base of the kiln is heavy steel reinforced by vertical double angle iron posts. Plate XXIV. shows the design of the Keystone kiln with plates cut away to show the interior arrangement. The steel cooling cone within the supporting basal cylinder is made of heavy boiler plate suspended from a heavy cast-iron bed plate and can be readily removed for repairs. At the bottom of the cooling cone are patented draw gates opened and closed by hand wheels which project outside of the supporting base so that the workman can turn the gates without coming in direct contact with the hot lime and dust.

The heat for the kiln is generated in four independent furnaces, each 24 inches wide, 30 inches high, and about four feet long. The furnaces can be used with forced draught under the grate bars by forcing a mixture of steam and air through an

1. Broomell, Schmidt & Steacy Co., York, Pa.

inserted steam pipe shown in the illustration. Induced draught is obtained by using an iron cover with a door and attaching a suction fan to the top of the kiln.

The shell of the kiln is composed of heavy steel plates bolted together, and the interior is lined with fire brick supported by common brick. Near the top of the kiln as shown in the illustration, is placed a heavy steel cone to protect the brick, and above this cone is a large storage space the full diameter of the kiln. The rock is heated in this space by the heat passing through the kiln and its temperature is gradually raised as the rock passes down to the burning zone.

These kilns are usually placed in a row or battery with three feet of space between them, and any kind of fuel may be used. The most popular sized kiln is the No. 3 which is described as follows by the company:

Diameter of shell outside.....	11 feet 6 inches
Diameter of brick lining inside.....	6 feet 6 inches
Diameter of cooling cone at the top.....	7 feet.
Diameter of cooling cone at bottom.....	2 feet.
Height of cooling cone.....	7 feet.
Total height of kiln.....	48 feet.
Shipping weight of kiln.....	44,000 pounds.
Weight of special brick.....	14,800 pounds.
Fire brick required.....	8,463
Common red brick.....	15,700
Capacity—90 to 140 barrels (200 lbs) of lime per 24 hours.	

O'Connell Kiln.—The O'Connell kiln¹ patented in 1899 has boilers set in the arches of the kiln, and the fire box of the furnace opening into the body of the kiln supplies the necessary heat for the kiln and also provides a means whereby steam generated in the boiler may be utilized to aid combustion. By this plan the fuel used for burning lime produces also steam to run the blowers and conveyors, elevate the stone, and operate quarry pumps and other necessary machines. It is claimed to save 20 per cent. of the fuel ordinarily required for burning the lime.

Hoffman Kiln.—The horizontal circular kiln invented by Hoffman, used especially for manufacture of brick in Europe, is also used for lime burning. The kiln has been used for both purposes at the same time. It consists of an arched circular room divided by movable partitions into sections (usually 12 in number). The limestone is placed in these sections and fired through

1. *Rock Products*, Vol. II., No. 8, p. 11.

openings in the roof into the first section, and when the lime is burned the fire is added to the next section and so on around the circle. The air enters the section in which the lime is being removed and cools the burned lime, becoming heated in the section where the full fire is maintained and then reaches the sections charged but not burned giving off its heat and passes from the last section out through a chimney at the center of the kiln. Dampers serve to regulate the air current and sections not in use can be shut off as all are connected with the central chimney by openings which can be readily closed.

In England, according to Frasc¹, the Hoffman kiln produces daily 1200 to 1500 cubic feet of lime with a consumption of only 5 pounds of slack coal per cubic foot of lime. In Germany the saving of fuel in the Hoffman kiln is almost 75 per cent. over the old methods. The lime is said to slake more easily and cannot be stored for so long a time as that made in other kilns. The saving in fuel in Hoffman kiln over the best constructed draw kilns is said to be about 40 per cent. This form of kiln could be used with economy where the lime is hydrated before being placed on the market. While the method is popular in England and Germany, it has not as yet attracted special attention in this country.

Rotary Kilns.—The fact that vertical draw kilns were formerly used in the manufacture of Portland cement, while at the present time rotary kilns are found to be better adapted to this work, has suggested a reform in lime burning by the use of rotary kilns. There has been considerable theoretical discussion of the subject, and much difference of opinion among engineers whether there is any economy involved. Competent engineers have reached opposite conclusions while the few practical trials have not been conclusive.

The California Portland Cement Company² burned lime in a rotary kiln using oil fuel. The limestone was first crushed and run through screens to a size of two-thirds to one and one-fourth inches in size, and it was found that the extra cost of crushing overcame any reduction in fuel cost. The fuel consumption, labor cost, and other data in this work in California are given as follows by A. E. Truesdell:¹

1. Frasc¹, Mineral Industry, VII., p. 491.

2. Rock Products, Vol. IV., No. 1, p. 35.

Length of rotary kiln.....	70 feet.
Average output.....	25 tons lime per day.
Fuel consumption.....	40 barrels (42 gal.) per 24 hours.
Specific gravity.....	17.21 Baume.
Stone.....	98.5 per cent. carbonate of lime.
Labor employed.....	2 crushers, 2 millers, 2 burners, 3 wheelers.
Labor cost.....	\$22.00 per day.
Weight of oil as 7.8 pounds per gallon equal 13,104 pounds per day or 26.2 pounds oil per 100 pounds lime.	
One pound oil; 11,300 calories or 296,000 pound calories per 100 pounds of lime equivalent to 39.5 pounds of coal (7,500 pound calories) to pound.	

The results of these trials show a much higher fuel requirement than theoretical calculations would give, as determined by Henry S. Spackman¹ whose results are given in the following table in pound calories to produce 100 pounds of lime from 173.4 pounds limestone containing 91.2 per cent. lime carbonate, and 3.78 per cent. magnesium carbonate:

Heat required to raise the limestone to dissociation temperature for magnesium carbonate.....	14,194.0
Heat required for dissociation of magnesium carbonate.....	1,395.8
Heat required to raise limestone to dissociation temperature for lime carbonate.....	14,450.0
Heat required for dissociation of lime carbonate.....	69,223.0
Total.....	99,217.8
Less heat recovered from carbon dioxide in cooling to stack temperature.....	8,355.6
Total theoretical heat required.....	90,862.2
Actual requirements based on 55.7 per cent. efficiency in kiln, the same as for cement.....	163,127.0
Calculated coal required, calorific value, 7,500 pound calories	21.7 pounds.

In ordinary kilns, as has been stated in another section, 300 to 500 pounds of coal are required to burn one ton of lime. By the figures of Mr. Truesdell on the work in California, 790 pounds of coal would be required to burn a ton of lime in a rotary kiln. According to the figures of Mr. Spackman, 434 pounds of coal would be required for a ton of lime, but he adds there would be a saving in labor cost, which in the California experience was found to be increased from 1.75 to 2 cents in usual methods to 4.4 cents per 100 pounds in using the rotary kiln.

During the past summer a rotary kiln 100 feet long and 6 feet in diameter, equipped with the Swindell gas producer, has been

1. Rock Products, Vol. IV., No. 2, p. 38.

installed for lime burning¹ by the New York Lime Company at Natural Bridge. The stone is crushed to one inch cubes and fed in a continual stream as in Portland cement manufacture. The waste heat from the kiln passes through a Crook vertical water tube boiler which will generate steam for use as power in crushing the stone and for turning the rotary kiln.

HYDRATION OF LIME.

Calcined lime leaves the kilns in lumps of varying size, one-fourth larger than the original mass of limestone when unbroken. When water is added to the lime oxide, it crumbles to a flour and the process is termed *slaking*. The resulting product is a lime hydrate which is soluble in water. The formation of the hydrate generates heat which, according to Frascch, may reach 150° C. (302° F.) charring wood or even setting it on fire.

Lime hydrate (CaH_2O_2) consists of 75.67 per cent. lime oxide² (CaO) and 24.33 per cent. water, with a specific gravity of 2.078². The specific gravity of the lime oxide is about 3.1, and of limestone about 2.8.

Frasch further states that the density of lime greatly affects its slaking, if burned under 1000° C. it slakes at once, but if burned at white heat it may require hours, also the lime slakes slowly with steam and more rapidly with hot water. In the use of cold water, the lime should be slaked by soaking with one-third the required amount of water and then add the remainder after the heat is generated. If too much cold water is added so as to chill the lime it will be granulated.

The volume of the lime and the weight are much increased by hydration, the weight being increased one-third in pure limes. According to the observations of Cook,³ one bushel of good stone lime weighing 93 pounds slakes to nearly three bushels, each of about 45 pounds weight; one bushel oyster shell lime weighing 60 pounds forms somewhat over two bushels of slaked lime, each weighing about 40 pounds; one bushel of magnesian lime weighing 80 pounds yields two bushels of slaked lime.

1. Rock Products, Vol. IV., No. 5, p. 45.

2. Frascch, loc cit.

3. New Jersey Agr. Expr. Station 1881, p. 31, quoted Penn. Ann. Rept. Depart. of Agr. 1900, p. 231.

According to Frasch¹ the amount of increase in bulk depends greatly upon the mode of slaking. If the total amount of water is used at once during the slaking the increase in volume may be three and a half times the volume of lime. If permitted to fall to powder before rest of water is added, the increase is only two and a half times, while slaking in air, the increase is 1.7 times.

Old Methods of Hydration.

The ordinary method of slaking lime, according to Gilmore,² is termed *drowning*, and consists in pouring the necessary amount of water over the lumps of lime in a water tight wooden box or in a basin made of sand coated over on the inside with lime paste to make it impervious. The layer of lime is six to eight inches deep and enough water is added to make a thick pulp. In five to ten minutes there is a rapid increase in volume, evolution of vapor, and marked rise in temperature. A layer of sand is then spread over the lime to hold in the heat and vapor and thoroughly slake the lime.

This is the common method of hydration or slaking in use in this country, and when the proper precautions are taken, the resulting product will be uniform and good. Careless work in this process will injure the product and result in inferior work. Too much water will give a nearly fluid paste of lower strength. If too little water is added at first, and the additional quantity is added later it is apt to chill the lime in process of slaking and give a granular product. If the lime is stirred during the process of slaking it does not form as fine product as the action of slow absorption of water.

Unburned cores and over-burned lumps will remain unaltered in the lime paste, these are usually removed by passing the lime putty later through screens in the end of the mortar box composed of wood or iron slats. Such a method will remove the larger masses but small particles are apt to be included in the mortar unless very fine screens are used. Any lime particles not fully slaked will later cause trouble in the mortar bursting in the wall forming scales or broken places.

Another method of slaking described by Gilmore is the process of *immersion* which consists of suspending the quicklime pre-

1. Loc. cit., p. 495.

2. Limes, Hydraulic Cements and Mortars, p. 179.

viously broken into small fragments in a basket in water for one or two minutes, withdrawing it before the reduction begins. The lime is then heaped together and covered up to concentrate the heat and prevent escape of vapor. The lime in this process breaks into a fine powder which may be kept for several months if not in direct contact with the atmosphere. The method is modified by forming heaps of the lime fragments and sprinkling them with one-fourth to one-third their volume of water, after which the lime is covered with the sand to be used in the mortar. It should stand for one or two days, and in southern Europe, according to Gilmore, the quality of the lime is supposed to be improved by allowing the heaps to remain several months.

Air Slaking.—When caustic lime (CaO) is exposed to the air, it absorbs moisture and falls into a powder. The action is slow and not accompanied by any great rise in temperature. The time required for complete air slaking varies with the character of the lime, but the process usually requires several weeks and in some limes the lime is not completely slaked for months.

During this process carbonic acid is absorbed from the air and a certain part of the lime is changed to carbonate thus lowering its strength. In one year the layer of carbonate, according to Vicat¹ reaches .10 to .12 of an inch in depth.

New Methods of Hydration.

As has been stated, lime may be slaked by ordinary methods, giving a uniform and high class product, but through carelessness of the workmen or haste used in the work, a poor product may result. As a rule skilled workmen are not employed in this part of the work, and a cheap and satisfactory method of slaking lime has attracted the attention of lime men and led to a considerable amount of experimental work culminating in a series of patents for making a slaked lime which can be sold direct to the plasterers and masons. This product is sold under the various names of lime hydrate, limoid, new process lime, cream of lime, etc.

There are a number of processes in use for manufacture of hydrated lime, two of which will be described.

The new method used by the Clyde Iron Works of Duluth, Minnesota, is now in process of installation at the plant of the Harpers Ferry Lime Company at Millville in this State. Figure

1. Gilmore, loc. cit., p. 187.

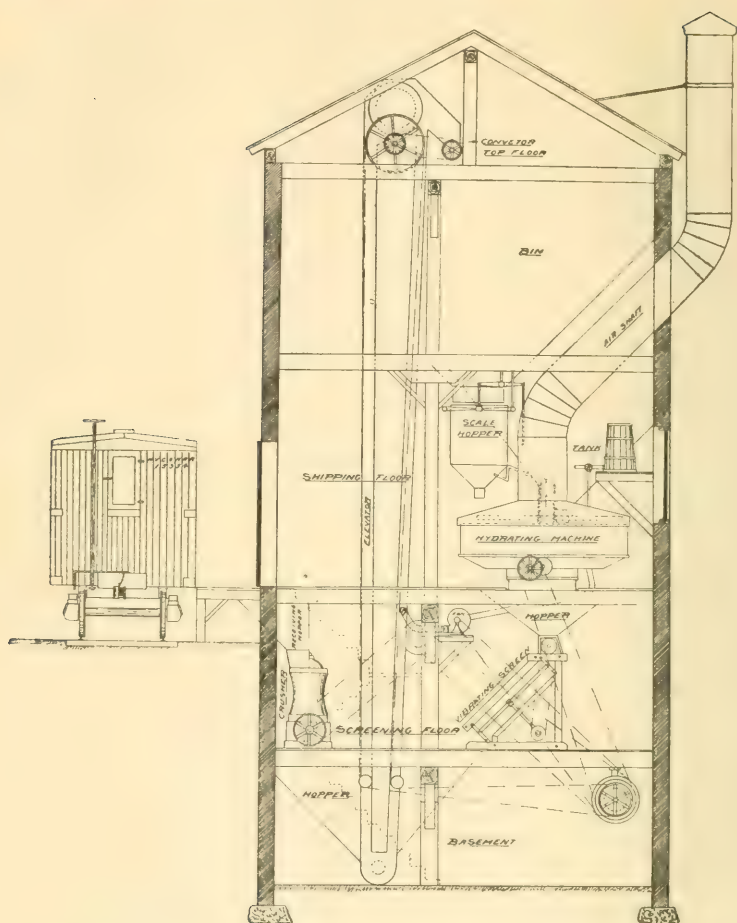


Fig. 35.—Sectional View of the Clyde Iron Works System for Hydrating Lime.

35 shows a sectional plan of this system. The first stage of the process is *crushing*.¹ The large lumps of lime are reduced to a size of one inch or less by an ordinary rotary or pot crusher so as to secure a uniform product giving uniform results in slaking. After crushing, the lime is elevated to a bin over the hydrating machine and weighed before going into the hydrating machine.

In the second stage, *hydrating*, the crushed lime is drawn from the bins into a hopper scale in 1000 to 2000 pound lots care-

1. Description furnished by the company.

fully weighed, and from there dumped into the hydrating pan where a scraper operated by a hand wheel automatically levels the lime to a depth of about seven inches. This pan (see figure 36) revolves so that every particle of lime is brought into con-

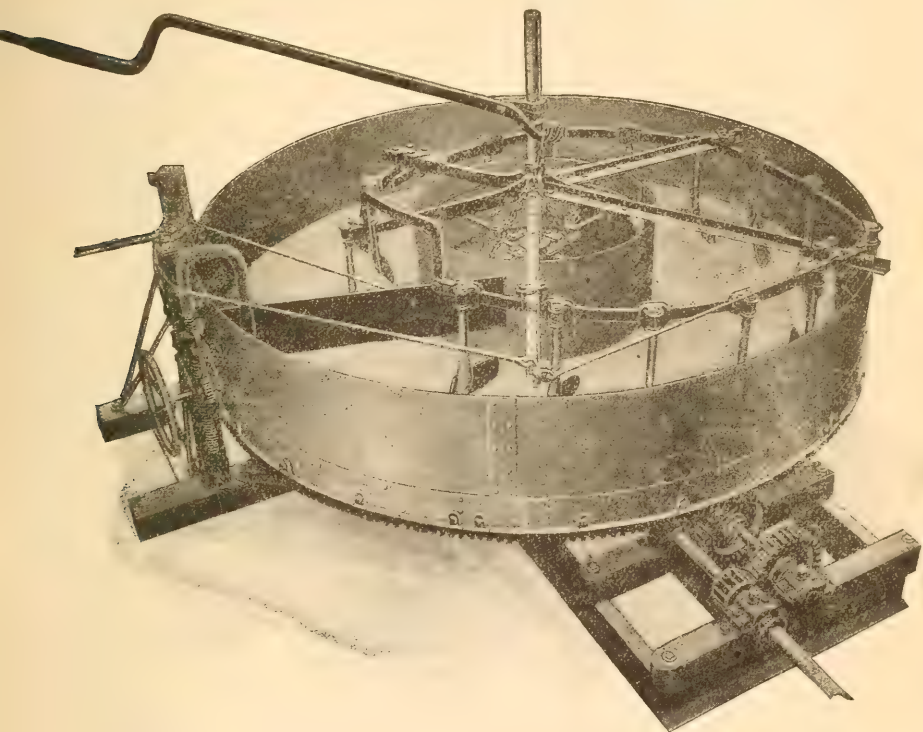


Fig. 36.—Lime Hydrating Pan Used in Clyde Iron Works System.

tinuous contact with a series of stationary right and left hand plows so arranged as to insure a thorough turning over every half revolution.

The automatic sprayer is located over the pan so as to evenly sprinkle the lime as it revolves beneath and is connected by a three-way valve to a tank above which holds a predetermined amount of water, just sufficient for each batch. After the spraying is completed the closing of the valve permits a given quantity of water to enter the tank for the next batch. The hydration is completed on high magnesium limes in about one and a half minutes and with high calcium limes in a half minute.

As the pan revolves the lime is turned over by the scrapers, thoroughly mixing the particles with the proper amount of water until the heat generated evaporates all the free moisture leaving the lime as a fine impalpable powder with a maximum temperature of 200° F., after which the temperature rapidly decreases and when cooled, the center cylinder of the pan is raised and the lime is scraped into the opening which leads to a receiving bin, and the pan is ready for the next batch.

In the third stage, *screening*, the hydrate with its impurities as unburned cores, clinkers, etc., is discharged from the bin over screens having a capacity of 3000 pounds. The lime is screened to a fineness of 40 to 200 mesh, the pitch of the inclined screen determining the fineness. Air separators may be used in place of screens. After screening, the lime is elevated into storage bins from which it is drawn into barrels or sacks.

The following data give the size, capacity, etc., of the hydrating pans and screens:

HYDRATING PANS.

No.	Diameter of	Height of pan.	Capacity per batch	Pulley.	Speed Rev. per minute.	Weight.
2	8 ft. 0 in.	10 in.	1000 lbs.	6x24 in.	175	4500
3	10 ft. 6 in.	20 in.	2000 lbs.	6x24 in.	175	6800

SCREENS.

No.	Width over all.	Length over all.	Height over all.	Size of driving pulley.	Speed of main driving pulley.	Size of screening surface
1	7 ft. 3½ in.	6 ft. 11¼ in.	7 ft.	12x4 in.	250 Rev.	4x6 ft.
2	11 ft. 3½ in.	6 ft. 11¼ in.	7 ft.	12x4 in.	250 Rev.	8x6 ft.

Another patented hydrating machine of an entirely different pattern from the last is made by the American Hydrating Company, of Baltimore, Md., and the following description is taken from their catalogue. The machine shaped like a rotary kiln consists of an outer steel cylinder 7 feet in diameter and 30 feet long, at the upper end of which is a smaller extended cylinder, 6 feet long and 3 feet in diameter. (Illustrated in plate XXV).

The large cylinder contains screens which taper toward the lower or discharge end. These screens and cylinders revolve together around their common axis and are supported by circular tracks which encircle the large cylinder and rest on rollers beneath, all being revolved by cog gearing. At the end of the small cylinder is a stationary plate through which passes a chute for charging the lime. This chute is closed by a door opening inward when the lime is added. The door has a lever connected by chain to the lever of a flush tank above and from which there is a pipe leading to a spray attachment in the smaller cylinder. The tank has an automatic valve closing the water inlet when enough has flowed in for a lime charge.

The lime is moistened by the spray in the smaller cylinder and passes along the incline to the inner coarse screen of the large cylinder, which is the continuation of the small cylinder, having openings one inch by three-sixteenths in size. The lime here slakes and breaking up passes through the screen to the next fine screen with openings one inch by one-sixteenth to the outer cylinder from which it passes out at the discharge end in a fine flour ready for packing in sacks or barrels.

There is an inclined perforated steam pipe which enters the lower end of the machine and extends through the axis, supplying steam to the interior and accelerates the hydration. The capacity of the machine is 5 to 8 tons per hour, requiring 1 to 5 H. P., and the weight is about 17 tons. This machine is used and highly recommended by the Scioto Lime & Stone Co., at Delaware, Ohio.

The discussion of uses and advantages of hydrated lime is given in the chapter on uses of lime.

Cost of Lime Manufacture.

The cost of manufacture of lime will vary in different sections, on account of amount and cost of fuel required, labor cost, size of plant, etc. Under average conditions in this State in a two-kiln plant with a daily capacity of 500 bushels of lime, the cost would probably average $5\frac{1}{2}$ to 6 cents a bushel, with the expenses distributed as follows:

Interest on plant and land.....	\$ 1.60
Repairs, taxes, etc.....	1.30
Quarry cost of 30 tons of rock.....	7.00
Fuel cost (coal \$1.25 a ton).....	5.00
Additional labor cost.....	12.00
Total cost of 500 bushels.....	\$26.90
Cost per bushel.....	5.4 cents

Lime is packed in sacks and barrels, or is loaded into the car as bulk lump lime. It is sold by the bushel, which varies in weight in different sections of the country. The legal weight of a bushel of unslaked lime in Ohio and Michigan is 75 pounds, in Virginia, Georgia, Illinois, Iowa, Kansas, Nebraska, and Colorado, it is 80 pounds, and in Pennsylvania, 72 pounds. The average weight of a bushel of lime in 22 plants of Pennsylvania was 76.2 pounds.¹

In slaked lime there is a gain of 42 pounds from a bushel of high calcium lime which weighed 93 pounds, and 20 pounds from a bushel of oyster shell lime weighing 60 pounds. One bushel of magnesian lime weighing 80 pounds showed no gain in weight in the Pennsylvania experiments, but had double the volume.

1. Report Penn. Depart. Agriculture, 1900, p. 226.

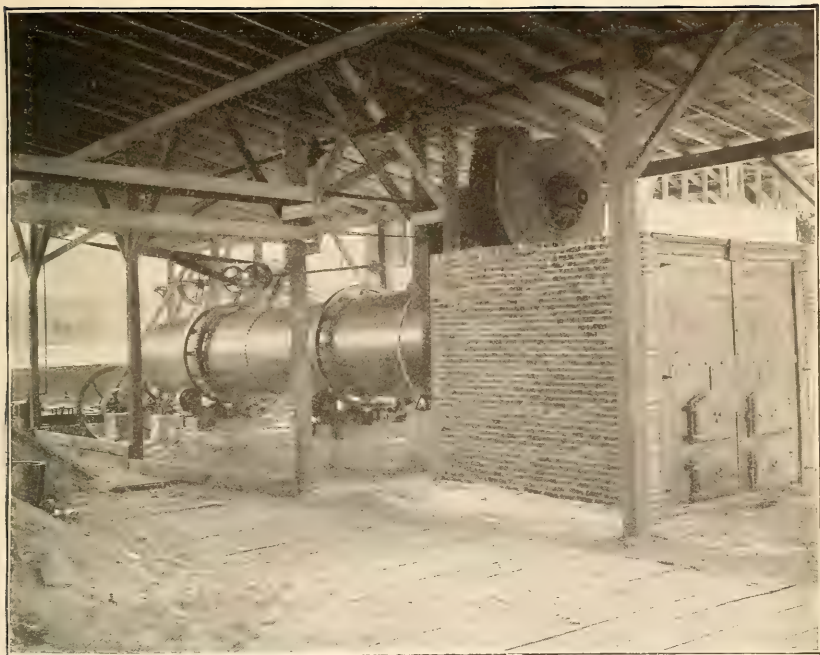


Plate XXVII-a.—Ruggles-Coles Rock Dryer.

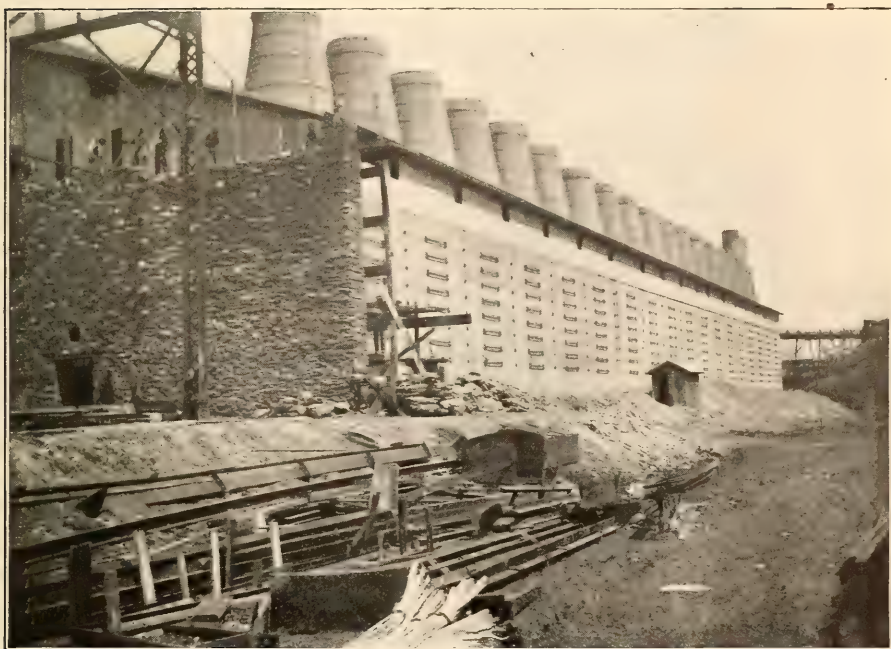


Plate XXVII-b.—Dome Cement Kilns (From "Cement Age.")

CHAPTER XVI.

THE USES OF LIMESTONE AND LIME.

LIMESTONE.

Building Stone.

Limestone is one of the popular building stones in sections where it is convenient to market, and is of good quality and color. Pure limestones are more popular than dolomites, and are usually more durable, as the open texture of ordinary dolomites gives access to the weathering agents which result in their disintegration.

The oolitic limestones are especially popular for fronts and trimmings of fine buildings, and are shipped long distances from the quarry. The best known oolitic limestone in this country is the Bedford county, Indiana, stone which is shipped to all parts of the United States.

Marble represents the crystalline variety of limestone and is the most valuable variety. Marble fronts and trimmings are characteristic of the buildings in the eastern cities, and special varieties of Italian marble are shipped to all parts of the world. There is no true marble in this State, but in a number of sections there are local beds of very hard limestone which will take a fairly good polish, and are known as marble. The development of such deposits may meet with some success in markets not far removed from the quarry location, but will never reach any large market in competition with well known varieties.

The limestones of West Virginia have not been used to any great extent in buildings except for foundations, although some of the quarries would yield a durable and beautiful rock. The oolite of the southern part of the State in Greenbrier county is crushed into ballast or burned into lime, while it might be a much better source of revenue if used for ornamental work.

Road Material and Ballast.

Limestones furnish a supply of good road material in many parts of the country. Nearly all varieties of limestones are used in this work, but those which show good wearing quality combined with cementing properties are the best.

A number of limestone counties in this State are noted for the fine condition of their roads. Berkeley, Jefferson, and Ohio counties, which possess a large quantity of limestone, have the best county roads in the State. Other counties with probably as much limestone have very poor roads. This fact is illustrated by many of the counties along the line of the great Greenbrier limestone. With a large quantity of limestone readily and cheaply quarried in a county, there is little excuse for the poor roads so characteristic of certain sections of this State. A small outlay of money by the county each year would prove a profitable investment for the people.

The subject of good roads has not attracted the attention it deserves in this State, while it has become a most important problem in the adjoining state of Maryland, which is spending large sums of money on the improvement of county roads through appropriations made by the State and separate counties.

While there is a great variety of rocks used for road materials, a number of which are to be found in this State, good limestone is one of the valuable sources of supply, and this State has a large supply of such limestone near railroad lines that has not been quarried or used. Limestone in the hills yields little return to the State, but when quarried and made into good roads, proves a source of pleasure and great profit to its citizens.

The State of West Virginia to-day could do no greater favor to the farmers, nor make a more profitable investment than to authorize and appropriate a reasonable sum of money for the investigation of road materials in the State, to be followed by appropriations in co-operation with county subscriptions for the building and maintenance of good roads in the different parts of the State. Full details of all road materials in every county will be published by the State Geological Survey.

Large quantities of limestone are used with cement, for concrete. The lime rock is crushed to a gravel, or for special grades of work to a flour. The larger portion of the limestone quarried

in this State is crushed for railroad ballast. Train loads of this ballast are sent out daily from the quarries of the eastern part of the State. A large part of the Baltimore & Ohio road bed is made of this limestone, as well as the road beds of the other railroads in eastern and southern West Virginia and in Virginia. Limestone sets into a firm, solid bed and has proved durable for this purpose.

Lime and Cement.

Limestone while not the only source of lime form the source of the great supply. Some lime is made along the coast from oyster shells, and in a few sections from deposits of marl. Both pure limestones and dolomites are used.

Natural hydraulic cement is made from impure limestones which in the course of their formation have become contaminated with a considerable quantity of sand and clay mud, represented in the rock by silica and alumina. Such limestones have been valuable resources in the past, but at the present time have been to a large extent supplanted by artificial mixtures forming the Portland cement.

Portland cement, made usually from a mixture of limestone and clay or shale, represents a valuable use of limestone, and the industry is at the present time passing through a wonderful growth and development. In this artificial mixture three times as much limestone as clay is usually required.

The limestone must have the proper composition so that all limestones are not adapted to the work, but as is shown later, this State is rich in limestone adapted to the manufacture of Portland cement. The detailed discussion of the use of limestones for lime, natural cement, and Portland cement is given in other chapters of this report.

Furnace Flux.¹

Limestone is used in small quantities as a flux in cupolas where iron is melted for use in Bessemer converters. It is used in large quantities in all blast furnaces as a flux as well as in all basic open-hearth steel furnaces. For blast furnaces limestone higher in silica than is preferable for open-hearth work can be used, but not over 4 per cent. is desired. In blast furnaces some

1. Information furnished the writer by Mr. Frank S. Slocum of the Jones & Laughlin Steel Co., of Pittsburg.

prefer to burn the limestone to expel the carbonic dioxide gas before using, but it is generally used in the raw state.

In the open-hearth work, stone is preferred under one per cent. silica. In this process the limestone is used either in raw state or as burned lime, but generally raw. The composition of a good limestone for open-hearth work is as follows:

	per cent.
Lime carbonate.....	96.20
Magnesium carbonate.....	1.50
Silica	0.80
Alumina and iron oxide.....	1.50
Sulphur	0.020
Phosphorus	0.005

The limestone for blast furnaces should be low in phosphorus, about 0.020 per cent.

Dolomite being a highly refractory material on account of the large percentage of magnesia it contains, is used for lining basic Bessemer converters, a process which is not used in the United States to any large extent at the present time.

It is also used quite extensively in the open-hearth practice for making up the hearth of the furnace. Some works use it exclusively for this purpose instead of magnesia on account of the latter being so costly. Dolomite is always burned to expel carbonic acid before use in this process.

In England, dolomite is used quite extensively as a flux in blast furnaces, but in this country it is only used when limestone is not available or the price is prohibitive. The Pittsburg district uses a very small quantity in blast furnaces. In some plants the dolomite is used for patching or for making up the slag line of a furnace. The dolomite should have a low percentage of silica and a high percentage of magnesia.

The following analyses represent the composition of a good dolomite and the calcined rock or lime:

DOLOMITE ROCK.

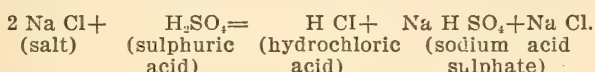
Lime carbonate.....	54.76
Magnesium carbonate.....	41.20
Silica	1.50
Alumina and iron oxide.....	2.10
Phosphorus	0.025
Sulphur	0.118
Moisture	0.150

DOLOMITIC LIME.

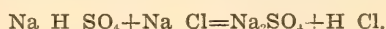
Lime oxide.....	56.29
Magnesia oxide.....	37.50
Silica	2.33
Alumina oxide	4.07
Phosphorus	0.036
Sulphur	0.172

Manufacture of Sodium Carbonate (Le Blanc Process.)¹

The manufacture of caustic soda by the Le Blanc process consists of two stages. In the first stage, common salt is converted into sulphate of sodium by the action of sulphuric acid, producing the acid sulphate of soda according to the formula,



but at a higher temperature, the acid sulphate decomposes the remainder of the salt forming a normal sulphate of sodium.



In the second stage, the sulphate is mixed with limestone and coal or charcoal and calcined in a reducing flame forming a mixture of lime sulphide (CaS) and carbonate of soda, the oxygen passing off as carbonic dioxide, shown by the following formula,



The sulphide of lime is practically insoluble in water so the carbonate is extracted by leaching with water at moderate temperatures (below 160° F.)

Lime Chloride From Limestone.

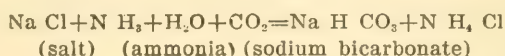
The chloride or muriate of lime (CaCl₂) is prepared in one process by dissolving marble or limestone in dilute hydrochloric acid. The solution is concentrated by evaporation and on cooling deposits crystals of lime chloride (Ca Cl₂, 6 H₂O) which heated to 200° C., lose two-thirds of the water, leaving a porous lime chloride used as a drying agent in chemical laboratories. If heated to redness in a platinum dish (to 720° C.) it loses the rest of the water, fusing to an anhydrous salt (CaCl₂) which on cooling forms a stony mass, a very powerful dehydrating agent. At

1. Encyc. Britan. Vol. XXII., p. 242.

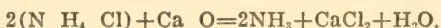
the present time lime chloride is produced as a by-product in the Solvay soda ash process sufficient to more than supply the market demand.

Solvay Process for Soda Ash.

In the Solvay process for the manufacture of sodium carbonate and hydroxide from sodium chloride (common salt) limestone is used. The stone is burned in a special form of kiln, which is arranged for saving the gases high in carbonic dioxide. The excess of carbonic dioxide is passed into a concentrated solution of sodium chloride which has previously been saturated with ammonia. The reaction is brought about in a tower in which the brine flows down while the carbonic dioxide is forced up, and the temperature is kept down to 35 degrees C. The reaction is as follows :



The sodium bicarbonate is not as soluble as the rest of the constituents and can be separated on filters. The liquor containing ammonium chloride is treated with the lime obtained in burning for carbonic dioxide. This liberates the ammonia as a gas which is returned for further work in the process. This reaction would be



The waste liquor from this process contains mostly calcium chloride with some sodium chloride, and from this liquor the pure calcium chloride can be obtained by crystallization. The supply from the Solvay plants is far more than the demand so that much of it is wasted.

Extraction of Magnesia From Magnesian Limestone.¹

Two principal processes have been suggested for extracting magnesia from magnesian limestone. In the *Scheibler process*, the mixture of lime and magnesia left by burning magnesian limestone is made into a thick milk by adding sufficient water. Water containing ten to fifteen per cent. by volume of molasses is poured into this solution and the mixture mechanically stirred. The saccharate of lime is soon formed in solution while the magnesia

1. Cements, Limes, and Plasters, Eckel, p. 157.

is precipitated. The whole mass is passed through a filter press and the magnesia remains behind with a composition of 95.99 per cent., magnesium oxide. The molasses is recovered by precipitating the lime with carbonic dioxide, and the total loss of molasses in the operation is 5 to 10 per cent.

In the *Closson process*, 20,000 pounds of magnesium chloride are mixed with the lime-magnesia resulting from the calcination of 3000 pounds of magnesian limestone. Water is added to give a thick solution and the whole agitated. The result is a formation of lime chloride and magnesium hydrate, the latter is caught in the filter press and the former passes through in solution. The hydrate is washed and burned, giving one ton of magnesia containing 96.9 magnesium oxide. By a special process described by Eckel in the book quoted, the magnesian chloride is again formed by the use of calcined magnesian limestone, so that the loss of magnesium chloride in the process is only 5 to 6 per cent.

Sorel Cement.¹

Sorel's magnesian cement is made by mixing calcined magnesia with a solution of magnesium chloride. The cement is used as a binder in connection with briquetting in the manufacture of artificial building stones, tiles, grindstones, emery and polishing wheels. A good mixture according to Eckel consists of 25 parts of magnesium chloride (45 per cent. solution), 25 parts of magnesia (93 per cent. magnesium oxide), and 50 parts of water. About 5 pounds of this mixture will serve to cement 95 parts of stone, emery, etc. The resulting blocks are very solid and harden thoroughly within a few hours.

Carbonic Dioxide.

Carbonic dioxide (CO_2) is used extensively for charging mineral waters. It is usually made by the action of weak acids on lime carbonate, using marble or a limestone or dolomite. The gas is condensed by pressure and packed in air tight iron or steel cylinders.

The gas can be condensed to a colorless liquid under a pressure of 50 atmospheres. The carbonic acid gas has a specific gravity of 1.529 and can be poured from one vessel to another.

1. Ibid, p. 162.

In some parts of England this gas is saved as a by-product in burning lime. In the ordinary kiln practice of burning lime a very large quantity of this gas is wasted, passing from the stack of the kiln into the air.

Manufacture of Glass.

Glass is made from a mixture of lime, sand or silica, and sodium carbonate (soda ash) or in window and bottle glass, sodium sulphate (salt cake). The lime is sometimes replaced by barium sulphate, or by oxide of lead.

West Virginia has become one of the important glass manufacturing centers on account of its abundant and cheap gas fuel, its large supply of pure limestone and high grade glass sand, and the soda is also made in large quantities at Wheeling. Thus, nearly all the requisite materials are to be obtained within the borders of the State and the plants can be located near main line railroads with comparatively short hauls to large markets.

Lime is used in most plants in the form of finely ground carbonate, but a number of companies use the burned lime or lime oxide, or the hydrate. The oxide and hydrate of lime absorb water and carbonic dioxide from the air, changing in composition and weight, which sometimes give trouble in mixing in correct proportions. The limestone must be as nearly pure as possible. Any iron impurity has a tendency to color the glass and magnesia is said to render the mixture more infusible. According to Linton¹ a high proportion of lime in the glass renders it hard and brittle, requiring additional amount of labor to work, and great care in the annealing process. This author gives the following composition of limes used in glass manufacture, to which is added an analysis of the Martinsburg limestone. This latter rock is crushed very fine by the Standard Lime & Stone Company, and reaches a large market among the glass plants.

	Prussia.	Pennsylvania.	Martinsburg.	
Lime carbonate.....	95.75	97.23	95.44	99.36
Magnesium carbonate	1.00	1.48	2.51	0.23
Iron oxide.....	0.33	0.16	0.69	0.31
Alumina	0.52	0.02		
Silica	0.84	1.01	0.60	0.79
Alkalies	0.85	....	....	....
Moisture	0.61	....	0.69	0.31

1. Min. Industry, Vol. VIII., p. 235.

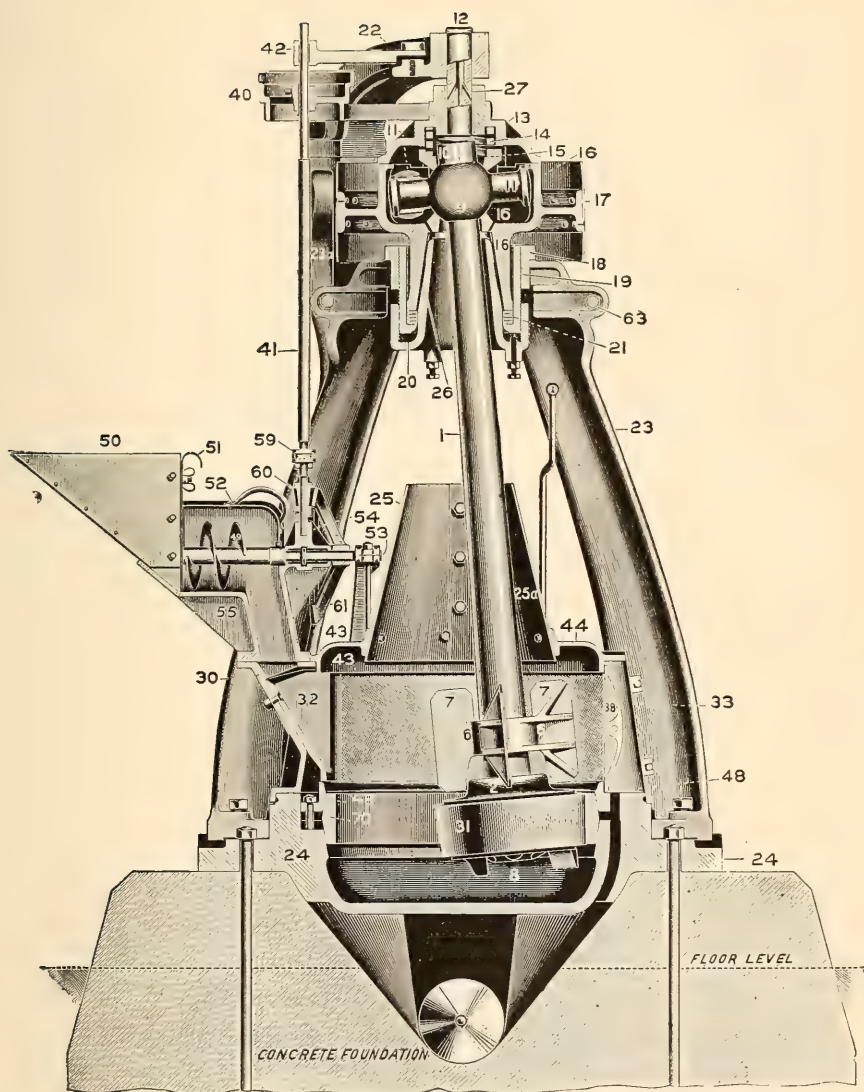


Plate XXVIII.—Griffin Cement Rock and Clinker Grinding Mill.
Sectional View.

To illustrate the mixture for window glass, the following materials are used in one of the Kansas plants :

Sand	100 pounds,
Salt cake.....	36 pounds, (require about 65
Lime oxide.....	36 pounds, pounds pure lime-
Arsenic	5 pounds, stone).
Carbon	4 pounds.

According to Mr. Joseph D. Weeks,¹ "Lime glass cannot compete with lead glass in brilliancy, but it is harder, not so easily scratched, holds its polish longer, is more elastic and consequently tougher, will stand higher temperatures, resists the action of water and chemical agents, and is very much more cheaply produced."

In the manufacture of lime-flint glass used for the finer grades of bottles, pressed table ware, etc., a dolomite is used in place of pure limestone.

Lithographic Stone.

The fine stone engraving work is done on a fine grained limestone, the best product coming from Solenhofen, Bavaria. Lower grades come from this country and have been used to some extent, but the main supply is imported. The limestone must be porous to absorb the ink, soft and uniform in texture so as to receive the finest lines of the engraving tools, and at the same time firm enough to withstand the pressure of the printing press. Such a combination of qualities is not common in limestones and when found gives to the rock a great value.

Statistics.

The following statistics of the limestone industry in the United States for 1904² will give some idea of the relative importance of the uses :

Lime made.....	\$10,431,100
Furnace flux.....	4,702,768
Building stone.....	4,543,760
Road material.....	3,714,937
Railroad ballast.....	3,153,002
Concrete	2,690,637
Rubble and rip rap.....	1,860,732
Paving and flagging.....	574,945
Miscellaneous uses.....	324,484

\$31,996,415

1. U. S. Geol. Survey, Mineral Resources, 1883-4, p. 968.

2. U. S. Geol. Survey, Mineral Resources for 1904.

The limestone used in Portland cement is not included in the statistics. The most important states in value of production in order of rank are Pennsylvania, Ohio, Illinois, Indiana, Missouri, New York, and Wisconsin. The order of rank of the leading states in the production of lime both in value and quantity is as follows: Pennsylvania, Ohio, Maine, Wisconsin, and Missouri.

According to the same authority the output in West Virginia for 1903 and 1904 was as follows:

	1903.	1904.
Furnace flux.....	\$243,135	\$244,535
Lime	166,332	197,652
Railroad ballast.....	148,446	98,105
Concrete		61,096
Road material.....		42,965
Building stone.....	81	10
Other uses.....	30	.....
	\$558,024	\$644,363

This State ranks fifth in the production of furnace flux, and eighteenth in lime output. The production of building stone is almost lost in the account. A study of chapter II. of this report on lime shows the resources of the State, a study of the above table shows the development of these resources, a vast difference and an excellent comparison to show a line of undeveloped mineral wealth. At the present time it is impossible to buy a supply of lime without thirty to sixty days' notice on account of the shortage on the market. There is an opportunity waiting for profitable investment in the limestones of this State whose value to-day is so little appreciated.

USES OF LIME.

If the use of limestone for Portland cement is excepted, over one-third of the value of the limestone quarried is represented by lime, which is used in a great variety of ways. The uses of lime oxide will be reviewed in this section.

Paper Manufacture.

In the manufacture of paper¹ from rags, straw, etc., it is necessary to thoroughly cleanse the materials and break the combination of cellulose with foreign adhering substances. This is

1. Clapperton, Practical Paper Making. Hoffman, Practical Treatise on Manufacture of Paper.

done by means of boiling in a caustic soda or lime solution. Lime is only slightly soluble in cold water, one part lime oxide dissolving in 700 parts of cold water; and it is less soluble in hot water, one part lime dissolving in 1200 to 1500 parts of boiling water. The dissolved lime in the paper making process unites in part with the non-cellulose portion of the stock. The fatty impurities and coloring substances are thus removed and leave the pure, softened fibre. The material is treated in large rotary boilers holding about 10,000 pounds of hot water so that eight pounds of lime are held in solution, but this quantity is rapidly taken up by the paper materials uniting with the fats to form insoluble lime soaps, and the water then dissolves more lime and so on until the reactions are complete. An excess of lime can be added in the boilers as it does no harm, while in the use of caustic soda great care is required to use the proper quantity as any excess will injure the fibres.

The lime should be white in color and in lumps which slake readily. If lime powder partially slaked is used it changes rapidly to the carbonate which has no caustic power and may adhere as a crust to the fibres and then is very hard to remove. Five to fifteen pounds of lime are required per 100 weight of rags, etc.

Jute is boiled with lime oxide under a pressure of 22 pounds to the square inch for ten to twelve hours and then allowed to stand loosely stacked in contact with an excess of lime, after which it is washed and boiled with soda ash. For all this work pure limes are used, impure limes require greater quantity and the pulp is said to be coarser, and much longer time is required in the process.

At the present time a large portion of the paper in use is made from wood pulp. The sticks of timber are fed into a cutting machine and the chips are reduced by chemical solutions to a pulp which is rolled into sheets for use in the manufacture of various grades of fine paper. There are two processes for the reduction of the wood to pulp.

The *soda process* is used on poplar, cottonwood, bass wood, and some hard woods, and is popularly regarded as making the best paper pulp. The wood chips are boiled in digesters, with soda ash (sodium carbonate), which is rendered caustic by use of pure lime oxide. After boiling for a number of hours, the pulp is washed, screened, and bleached with lime chloride. The

process requires about 20 tons of lime with 55 to 60 tons of pulp. The large mills at Luke, across from Piedmont, manufacture 20 tons of pulp daily.

The *sulphite process* is used with spruce and hemlock wood, and is the process used at the Davis, West Virginia, pulp mill which has a capacity of nearly four tons of pulp a day. Magnesian or dolomitic limes are required in this method, and for the most economical work the lime should contain over 30 per cent. of magnesia.

The wood chips are placed in the digester with milk of lime and sulphurous acid. In some mills the magnesian limestone is treated with the acid first, and this liquor added to the wood. In either case under the action of high heat applied, lime and magnesian sulphites are formed which remove the tar and oils, and soften the wood fibres. The pulp is then washed, screened, and rolled into sheets as in the preceding method. The magnesia of the dolomitic lime forming magnesium sulphite dissolves the non-cellulose matter more completely than the lime, and gives a stronger and more rapid reaction with these woods than pure lime.

Sugar Manufacture.

While lime is only slightly soluble in water, it is more soluble in sugar water, uniting with the sugar to form sugar of lime, an insoluble compound. Magnesia forms a soluble compound with sugar so the lime must be pure, thoroughly burned and slaked with pure water to a milk of lime, which is carefully filtered before use.

This milk of lime is added to molasses, forming the insoluble sugar of lime which is purified by washing with water or alcohol and then carried in suspension in pure water through which a current of carbonic dioxide gas is passed. The sugar enters into solution and the base is converted into the insoluble carbonate. Three to four per cent. of lime oxide in a very fine powder is mixed with enough water to form a cream, and this is added to the molasses at a temperature of 30 to 33 degrees C., (86° to 91° F.) The precipitate is broken and washed several times.

Lime is used with cane sugar solutions to unite with acids holding albuminous matter in solution, causing the impurity to coagulate and become insoluble thus clarifying the cane sugar

solution. Strontium is now used in many sugar refineries in place of lime.

Lime in Leather Manufacture.¹

Hides and skins are steeped in a solution of lime in order to remove the hair and at the same time swell the hide or skin ready for the reception of the tanning liquor. Rich or pure limes are required, and should contain less than 5 or 6 per cent. of impurities.

Use of Lime in Soap.

Lime is used in soap manufacture to change the soda ash or carbonate of soda to caustic soda. This reaction requires 60 to 65 pounds of lime to 100 pounds of soda ash. The lime must be pure, well burned and free from magnesia.

In the saponification of tallow² for soap, it is mixed with good slaked lime into a thin cream with water. This mixture is inclosed in a vessel and boiled with steam and agitated for three hours. The action of the lime decomposes the tallow, setting free glycerine, while calcium stearate and oleate are formed. These salts when mixed together constitute an insoluble soap and facilitates the subsequent separation of the solid and liquid constituents of the tallow. The tallow is sometimes bleached by boiling it in lead lined tanks with a solution of chloride of lime.

Manufacture of Candles.

Candles are sometimes made from the free organic acids which are usually combined with glycerine to form the fats. The acids have a higher melting point and so make better candles than the original fats.

Lime which is pure and caustic is used in the treatment of the fats to form a soap. This soap is then heated with sulphuric acid forming lime sulphate and free organic acids which solidify on cooling. The latter float above the lime sulphate and so are readily removed.

Gas Purification.

Lime was formerly used in the purification of artificial gas. The gas was passed over slaked lime which absorbed the carbonic

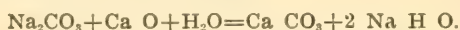
1. Davis, the Manufacture of Leather.

2. New York State Museum, Bull. 44, p. 669.

dioxide and the hydrogen sulphide gases. The lime was used in the hydrate form, and used in a moist condition. At the present time it has been replaced by ferric oxide in nearly all plants.

Caustic Soda (Na H O).

Caustic soda is prepared by treating a mixture of sodium carbonate with pure lime and water in agitator tanks. The reaction is represented by the formula,



The theoretical quantity of pure caustic lime required to render caustic 100 pounds of sodium carbonate (soda ash) of 48 per cent. strength, is 43 pounds, but on account of the impurities usually present, 60 to 100 pounds are required and usually the latter amount.

Manufacture of Acetic Acid.¹

The dry distillation of wood yields about 10 per cent of tar and 30 per cent. of an acid liquid which contains 10 per cent. of its weight in acetic acid. This impure liquid is distilled again and the vapors passed through milk of lime which absorbs the acetic acid forming acetate of lime, while the alcohol and other impurities pass on to the condenser.

Upon the evaporation of the acetate of lime there is formed the commercial gray acetate of lime. To obtain pure acetic acid from this compound it is heated in a copper still with hydrochloric acid, using great care not to add enough to combine with all the lime, as the free hydrochloric acid would attack the still.

Bleaching Powder.

Bleaching powder is made by exposing pure slaked lime to an atmosphere of chlorine until the lime will absorb no more chlorine. A mixture of peroxide of manganese, common salt, and sulphuric acid is sometimes used in this manufacture, the mixture being placed in a lead retort with a lead pipe to conduct the chlorine vapor into a chamber in which lime oxide is spread in a thin layer. There is thus formed a dry lime powder containing 30 per cent. or more of available chlorine. The lime must be of high degree of purity. The chief use of the powder is for bleaching vegetable fibres for textile and paper industries.

1. Thorp, Outlines of Indust. Chemistry.

Lime in Lead Smelting.¹

Lime has recently been used in the process of roasting galena (lead sulphide) to remove the sulphur by a process patented in 1897 by Huntington and Heberlein, but not established as a successful and economical method until 1905.

In this process the powdered ore is intimately mixed with a quantity of alkaline earth oxide, as calcium oxide, the quantity corresponding to its sulphur content. The mixture is heated to bright red heat (700° C.) in the reverberatory furnace in a strongly oxidizing atmosphere, and is then allowed to cool down to a dark red heat (500° C.) in an oxidizing atmosphere. It is next transferred to the converter and air passed through at a slight pressure. The mixture sinters together, sulphurous acid gas escapes, and it is gradually converted into a mass consisting of lead oxide, gangue, and lime sulphate, from which the lead is extracted in the metallic form by any of the ordinary methods in the shaft furnace.

The chemical explanation of the action of the lime in this process is not fully known. The inventors of the process thought that at the high temperature calcium peroxide was formed, and later cooling down gave up part of the oxygen to the lead. This theory is not accepted by experts who have carefully studied the process, and W. Borchers explained the reaction by formation of calcium plumbate. W. Maynard Hutchings regards the formation of calcium plumbate as doubtful and unnecessary, and believes lime sulphate is produced which serves as the oxygen carrier. A modification of the process made by Savelsburg converts the galena directly with the addition of limestone and water, without any previous roasting. In the Carmichael and Bradford process, gypsum is added to the charge in place of limestone.

Calcium Carbide.

Calcium carbide has become an important commercial product, which placed in water generates a gas that burns with a clear, bright flame. The gas is known under the name of acetylene, and the simple operation of its generation permits the use of gas lights in communities where ordinary illuminating gas

1. Eng. and Min. Jour. Vol. 80, No. 9, p. 398; No. 16, p. 726.

cannot be obtained. Small generators are made for use in a room, or larger ones furnish light for the house and grounds. Some small towns have established municipal plants. This process of supplying gas is convenient, cheap, and with the proper precautions, safe.

The manufacture of the carbide is controlled to a large extent in this country by the Union Carbide Company with plants at Niagara Falls and Sault Ste. Marie, Michigan, with a daily capacity of about 200 tons. The material is quoted at \$65 a ton in car load lots.

Calcium carbide¹ is made by two processes of electrical smelting, intermittent and continuous. In the former, coke and lime, finely ground and mixed in the proper proportion, are allowed to flow into and partially fill the crucible in which the electric arc has previously been struck. When the reaction is complete the full crucible is withdrawn and another substituted, the change occupying two to three minutes and being required only once in 10 or 15 hours.

In the continuous process a stationary crucible lined with carbon is used with an electrode nearly as large as the crucible. A much higher current density is used than in the other process and fine grinding of the raw material is unnecessary. There is complete fusion, the liquid carbide is tapped at short intervals, and there is no unreduced material as in the intermittent process. The output per electrical horse power per day is considerably less, so that this process is only more economical when power is comparatively cheap.

According to Nicolai, for the production of 100 kilograms of calcium carbide there would be required theoretically 87.5 kilograms of lime and 56.25 kilograms of carbon. In practice the best mixtures are 100 parts lime and 70 parts coke. One ton of carbide is obtained from 1.79 tons of the mixture. The larger part of the carbide on the market at the present time contains about 80 per cent. of calcium carbide.

E. A. Schneider states that a good carbide plant should produce 3.5 to 4 kilograms (7.7 to 8.8 pounds) of carbide per electric horse power during 27 hours, and the total cost of a plant util-

1. The following discussion is based on an article in *Mineral Industry*, Vol. VII., p. 101.



Plate XXIX.—Rotary Kiln for Burning Portland Cement.

izing 3000 horse power is estimated at \$120,000 outside of the electric power plant.

The lime should be pure with as low percentage of impurities as possible, and the coke should be low in ash and sulphur. In the eastern and southeastern parts of this State are deposits of pure limestone, and coke of good quality can be obtained a short distance away. Further, the water power is available for generating electric power. Investigation of these resources for the manufacture of calcium carbide has been made by interested parties and a new lime industry along this line may yet be established in the State.

Sand-Lime Brick.

In the manufacture of sand-lime brick about 5 per cent. of lime is used with 95 per cent. of sand. Both pure limes and dolomitic limes are used, but the best product is said to result from the use of the former. The development of this industry is recent, but the growth is remarkable and new plants are being erected in various parts of the country. A description of this industry has been given in chapter XI. of the preceding part of this report.

Mortar.

Slaked lime is mixed with two to four parts of sand and water to form mortar which is then used in structural work. This represents the greatest use of lime. High calcium and dolomitic limes are used and both make good mortars. The sand counteracts the shrinkage and also aids in the modification of the texture of the mass and in the absorption of the carbonic dioxide gas which causes the hardening of mortars. Lime mortar has been replaced to some extent by gypsum plasters in interior work and by Portland cement in exterior work.

PHYSICAL TESTS ON LIMES AND PLASTERS.

By F. F. Grout, Assistant Chemist.

The plasterer as well as the mason require a mortar which possesses the following constant properties, good color, strength, plasticity, or, as it is often called workability, correct time of setting, and low cost.

For use as mortar,¹ strength is generally more important than color. In interior work as plaster, the selection is often made on the basis of good color rather than strength. The quality of a plaster or mortar is determined by the kind and amount of lime and sand used, the method of slaking and working, the rate of drying, etc. It is difficult, however, to foretell the results of any given combination or method, and these unknown factors probably would explain the many discrepancies between laboratory tests of lime and the practical application of the plaster or mortar.

The substitutes for lime plaster which have come into prominence indicate that this material has not been entirely satisfactory. With calcined gypsum for plaster and cement for mortar, the demand for lime has been seriously lowered. The higher cost of gypsum plasters has not prevented their increased use, and it has become necessary for the lime manufacturer to improve his product and adapt it to new uses. Not many tests of lime can be found in the literature of this subject and there is an important field of research along the line of physical examination. The time allotted to this work has been limited and the report is to be regarded as preliminary. Our tests have been made to confirm some of those found in works on this subject and to try some suggestions that have been offered. For example, an attempt has been made in our laboratory to find whether the quality of lime made from a small sample of stone will conform to that made from large quantities in a kiln by the practical manufacturer, to determine the effects of various substances added to the lime and to the mortar; to determine the various conditions of mixing; also several methods of slaking were tried to determine the possible differences in the product from the various methods of hydrating lime.

We did not have access to a kiln in which to test the problems suggested, and the time was too short to arrange for tests at the kilns which are distant from this place (Morgantown). Careful tests of lime would require a year, or in fact several years, and the briquettes should be tested at intervals through the whole time.

1. The term mortar is commonly used for the mixture of lime, sand, water, and other ingredients, and may be used on interior walls, or for laying up brick and stone. In this discussion plaster refers to the mixture for interior walls and mortar to the mixture used by the mason in wall construction. (G. P. G.)

It is sometimes stated by manufacturers that two limes made from different rocks, which are alike in chemical composition may yet differ in their physical properties, one being a hot lime and the other a cool lime. Other factors may be involved, and it is known that when the lime has been burned at extreme temperature it hydrates much more slowly, and is therefore cooler. Dr. Grimsley suggested that the texture of the rock might have an influence on the lime. Two dolomitic limes (Choteau of Ash Grove, Mo.) were burned side by side, one being granular and fossiliferous, the other was compact, breaking with conchoidal fracture. Two high calcium limes (Delaware, Ohio,) were selected which show similar differences in texture and were burned in the same way. The limestones had the following composition:

	Choteau.	Delaware.
Lime carbonate.....	61.33	90.20
Magnesium carbonate.....	37.33	9.70
Silica	0.50	
Alumina and iron.....	1.00	

The limes were ground to the same degree of fineness and the heat evolved when they were mixed with an excess of water was determined, but no allowance was made for the heat of solution. The results are given below in calories:

1. Granular dolomite rock, lime.....	182
2. Compact dolomite, rock lime.....	71
3. Granular high calcium rock, lime.....	252
4. Compact high calcium rock.....	147

While the heat of the complete reaction in each group may be the same, there seems to be little question that the rise of temperature was sufficiently different to be capable of laboratory determination. Dolomites burn in practically all cases into cool limes, while high calcium limes would require testing before the quality of lime could be determined.

Another difference in the lime burned from different limestones is the ease with which carbonic dioxide is removed from the stone and the rapidity or slowness with which it is absorbed by the limes. Texture may also be an important factor in this connection.

The four limestones referred to above were burned in stages, removing the samples from the furnace only long enough to take an average sample after each stage of the burning. Carbon dioxide was determined in each sample. As the four limestones were

placed close together in the muffle and their relative positions frequently changed, it seems quite certain that any differences in the amount of carbonic dioxide in the pairs of samples at a certain stage were due to some physical property, such as texture. The percentages of carbonic dioxide at the different stages are given below:

	Unburned.	First stage.	Second stage	Last stage.
Granular dolomite.....	46.0	35.0	19.5	0.88
Compact dolomite.....	42.6	26.0	8.5	1.02
Granular high calcium limestone	43.0	34.0	14.0	1.36
Compact high calcium limestone	40.0	33.0	5.8	1.28

Absorption of carbonic dioxide in air slaking, by the high calcium lime was as follows:

	Fresh.	2 weeks.	4 weeks.	8 weeks.
Granular limestone lime..	1.36	24.0	29.0	29.0
Compact limestone lime...	1.28	18.5	20.0	21.0

The differences in limestones of very close chemical composition may therefore be determined in the laboratory by a study of the limes as suggested above.

The addition of various materials to mortars is the basis of numerous patents issued at home and abroad. Potassium sulphate improves the initial set of plaster. Salts like lime chloride or magnesium chloride form compounds with lime on the principle of Sorel cement.

The tests here recorded were made on the tensile strength of briquettes made as in cement testing. These were left in the air for three months and broken on a Fairbanks machine. The strength of a mortar tested in this way is much less than in joints in a brick wall, and the crushing strength in a cube of mortar is also much less than in joints. C. B. Smith, of McGill University, gives a table from which these figures are extracted:¹

	In joints.	In cubes.	In tension.
3 parts sand, 1 part lime, 1 week old.....	287	21	19
3 parts sand, 1 part Portland, 1 week old..	755	341	43

Although the Portland cement cube was sixteen times as strong as the mortar cube, the joint was only three times as strong. It seems that the advantage of Portland cement over lime in ordi-

1. Canadian Society of Civil Engineers.

nary use is not as great as in laboratory tests. The above figures were obtained by actually building a column of brick laid in mortar at the same time that cubes were made of the mortar.

Work was done to standardize the tests and to determine the points affecting the results when the same material was used as a basis of the mixtures. The consistency of the mortar when laid was found to have little effect within the range of readily workable material. An effort was made to develop a consistency similar to that used by practical plaster mixers. It was found that the dryness of the briquette when broken was essential for obtaining comparative results as shown by the following tests, where the results represent an average of six briquettes:

Dried at 100° C.....	85 pounds
Air dried.....	59 pounds
Soaked 5 minutes in water.....	53 pounds

Plasterers disagree on the question of the effect of letting the lime paste stand before adding sand, and after adding sand allowing the mixture to stand before using. These conditions were tested as follows, where the numbers refer to tensile strength in pounds per square inch:

Lime paste stood before adding sand.

Hours.....	0	3	6	16	19	23
Pounds	56	85	96	91	83	110
Pounds	56	82	105	99	113	122

Lime paste and sand mixture stood before molding briquettes.
(One part lime to 3 parts sand, average 3 briquettes).

Hours.....	6	12	18	24	30
A.	57	48	58	82	94
B.	75	102	85	94	102

A.—The tests made on a lime hydrate as sold on the market.

B.—Quick lime was used.

An increase in strength is shown when the lime paste is allowed to stand 24 hours before the sand is added. Probably the weakness of those made soon after water is added was due to a lack of thorough hydration and the unslaked particles later weakened the mass by their expansion.

The hydrate lime used in one series of tests was, however, supposed to be thoroughly hydrated before use, and its improvement on standing must be due to some other cause. The absorption of carbonic dioxide by a wet paste has been shown to be slow, so no weakening would arise from this cause.

There is a possibility that the lime paste slowly attacks the silica and that the colloidal silica formed adds strength. The results of various investigations on the reaction of silica and lime at low temperatures have been seriously questioned, and some other explanation may be required. High temperatures would be more favorable for the reaction. Two samples were tested, one kept at 50° C. and the other at 15° C. for some hours before molding into briquettes. An average of six briquettes is given below in pounds per square inch, tensile strength:

50° C. paste briquette.....	58
15° C. paste briquette.....	57

There appears to be little or no evidence of a reaction between lime and silica below a temperature of 50° C.

Plasterers are usually favorable to some special sands as giving a mortar more plastic and eventually stronger than others. The workability of the mixture is a matter for the practical workman to decide, as different men may prefer different qualities. The effects of sand on the tensile strength are shown in the following tests:

1 part lime, 3 parts river sand.	1 part lime, 3 parts crushed sandstone.	1 part lime, 3 parts sand and sandstone.
Pounds.	Pounds.	Pounds.
62	82	57
69	79	..
72	75	66
63	91	..
73	89	57
72	..	..
—	—	—
69	83	60

These two sands are in general use in this section of the State and most of the mortar is made with the crushed sandstone with a small addition of river sand to make it work more smoothly.

Clay is usually considered as not injurious in a sand for mortar, unless in large quantity, or objectionable through its color. The following tests were made on the tensile strength of lime and sand with clay impurity:

1 part lime, 3 parts pure white sand.	1 part lime, 3 parts of mixture: 85% sand, 15% clay.
63	81
50	68
63	75
66	70
50	..
—	—
58	71

It is possible that these results would have been reversed in case the mortars had been broken wet instead of being carefully dried, since the strength of unburned clay is so seriously injured by moisture it might weaken the mortar.

In making hard white finish mortar it is customary to increase the proportion of lime to sand as high as one part hydrate lime to one part sand, not only to make the coat whiter, but it is often claimed to make a stronger mortar. The following tests on tensile strength were made with lime mixed with different amounts of sand:

Sand.	1 part.		1½ parts.		2 parts.		2½ parts.	
1 part high calcium lime....	69	51	50	58	65	57	67	69
1 part hydrate pure lime....	50	50	100	60	36	38	51	52
1 part dolomite lime.....	40	57	52	58	77	93	80	92

The variability of these figures is probably due to shrinkage which causes cracks as in the case of lime paste with no sand, however, none was visible in the briquettes.

Any substance that can be found to increase the strength of lime mortar when added in small quantity and at a low cost will have a most valuable application to the lime industry and increase its popularity and use. As far as one can judge from the records, not much work has been done on this line, or if most available substances have been tried, very few of the experiments are found in published form. Potassium sulphate, which has been tried improves the initial set of plaster, but had little effect on its ultimate strength. We have tried the effect of salt residue, which is a mixture of magnesia and lime sulphates and chlorides, etc., which might possibly act like a Sorel cement. The following tensile strengths were measured on these mixtures:

Plain lime mortar.	Salt residue, 4 per cent. of weight of lime.	Salt residue, 8 per cent. of weight of lime.	Salt residue, 16 per cent. of weight of lime.	Sulphuric acid. 2 per cent. of weight of lime. 5 per cent. of weight of lime.	
66	68	64	65	58	66
63	65	65	75	62	72
50	101	62	90	63	54
50	101	60	65	..	61
63	..	..	120	..	..
58.4	83.7	62.7	83	61	62.6

While some of the briquettes with the additional chemical showed an increase in strength, there was no uniform improvement sufficient to make the additional matter valuable.

Hydrated Lime and Gypsum Plaster Mixture.—Hydrated lime is now used to some extent with gypsum plasters, and marked improvement in quality is claimed. In our laboratory a short time test of one month's duration has been made on hydrate lime and gypsum plaster mixtures in varying proportions. The workman can best determine whether the mixtures are more plastic and more easily worked than pure gypsum plasters. The following results show the effect on the strength of the plaster in one month's time :

ONE PART PLASTER TO THREE PARTS SAND.

Per cent. of gypsum plaster.....	0	50	60	70	80	90	100
Per cent. of hydrate lime.....	100	50	40	30	20	10	0
Tensile strength of mortar.....	57	115	111	109	117	151	202

The strength of the lime mortar is improved by the addition of an equal amount of gypsum plaster, and improved as much as it is on the addition of larger quantities, but does not approach the strength of gypsum plaster alone very closely. Other advantages may be of more value, but these have not yet been tested. The problem is certainly a very important one and it is hoped that we may be able to carry these tests further. Portland cement has also been used to increase the strength of lime mortar.

The hydration of lime before it is placed on the market is a growing industry and becoming very popular in many sections of the country. Claims are made for its market superiority over ordinary limes in mortar especially in the matter of greater strength so that a large amount of sand can be used, or less lime would be required to reach a certain strength than would be the case in the use of quick lime. In the tests given above on effect of allowing lime paste to stand before use, a commercial lime hydrate was used in one series. The average tensile strength of 15 lime hydrate briquettes was 68 pounds, while that of 15 quick lime briquettes was 92 pounds, so the claim of the advantage of greater strength of a lime hydrate mortar was not supported by our tests. Many claims are made for the lime hydrate which will not stand inspection, but the advantages are sufficient to make this industry a most valuable addition to the lime trade without adding any false or misleading claims.

It is claimed the lime hydrate can be stored in a dry place without deterioration, but a quick lime would also keep its good

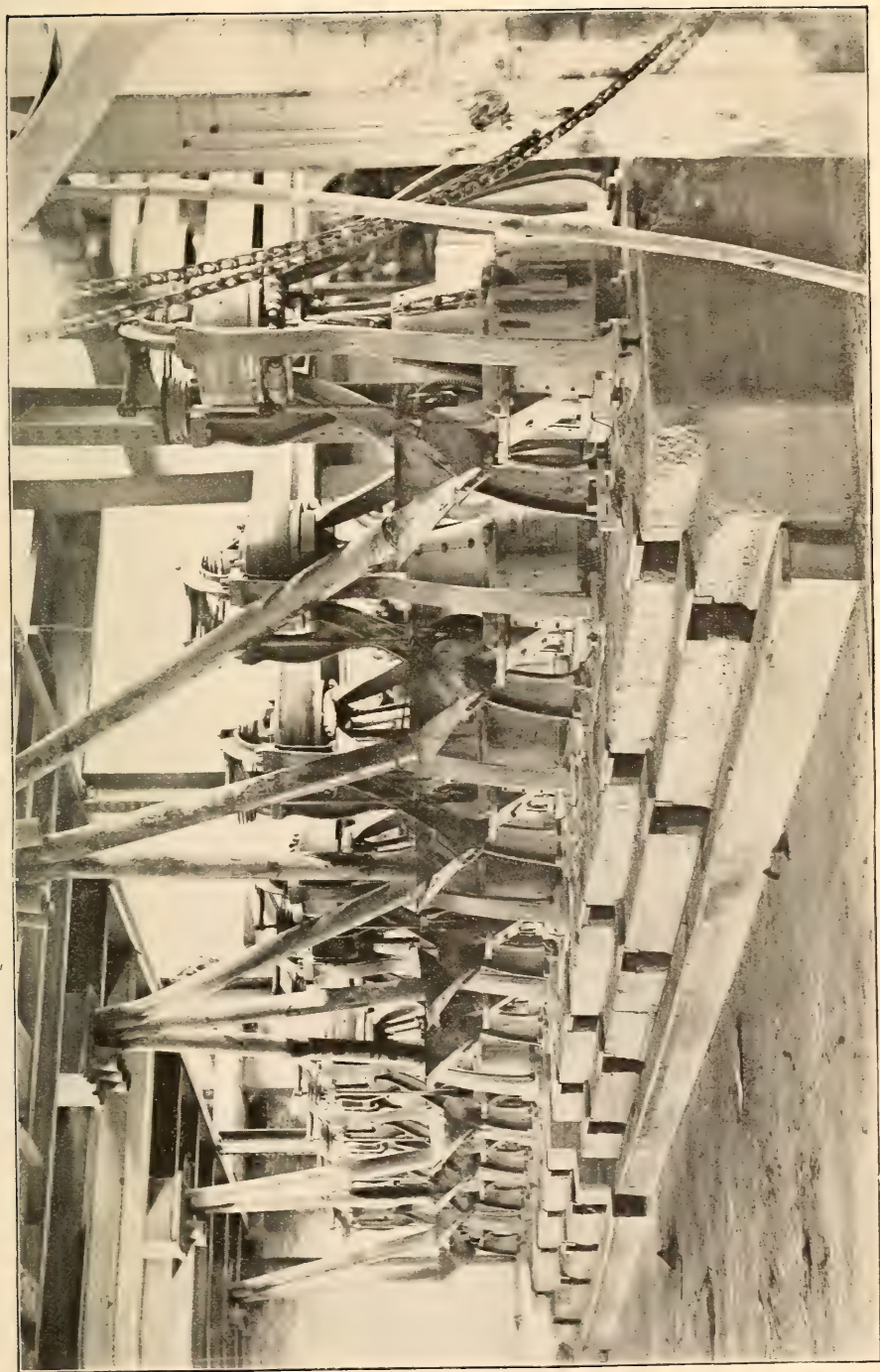


Plate XXX.—Battery of Nine Griffin Mills, showing Method of Installation.

qualities for a long time under dry air conditions. The exact nature of the deterioration of lime or lime hydrate when carbonic dioxide is absorbed seems to have never been determined. The theory that the hardening of mortar is a process of carbonation would certainly indicate that mortar would be weaker if the lime was carbonated before mixing with sand and water. It is also stated sometimes that air slaked lime makes as good mortar as any other. We have exposed to ordinary air some 15 samples of quick lime and lime hydrate¹ and determined the rate at which carbon dioxide and moisture are absorbed. Two samples of lime hydrate and the stone from which they were made were obtained from the companies referred to in foot note. The stones were burned in a small laboratory kiln and ground to a similar degree of fineness to the hydrate and carbonic dioxide determined at intervals, the two specimens standing side by side. The percentage of the carbonic dioxide is given below:

	1st day.	2 weeks.	4 weeks.	8 weeks.
Quick lime.....	0.33	20.71	26.76	26.77
Hydrate lime.....	6.42	28.16	31.26	31.27
Quick lime.....	1.52	20.98	22.94	24.06
Hydrate lime.....	2.42	17.96	18.38	18.73

The first sample of hydrated lime had a large percentage of carbonic oxide (CO_2) in it when first tested. Perfect hydration and screening should remove the underburned stone containing the CO_2 , and if the claim is true that very little or none is absorbed on storage there should be a very low percentage of this compound in the lime hydrate, but it is readily seen from the above that both limes absorb carbonic dioxide.

A small percentage of hydrochloric acid added to the lime increased the rate of absorption of the carbonic dioxide, suggesting that it might be of some service in the strengthening of mortar by ordinary hardening in short length of time.

A quantity of quick lime was carefully sampled and divided into three parts to see if the various methods of hydration affected the rate of absorption of carbonic dioxide. Not over three per

1. The lime and lime hydrates have been kindly furnished the Survey for these various tests in this section by the Ash Grove Lime Co. of Ash Grove, Missouri, and by the Scioto Lime & Stone Co. of Delaware, Ohio, the samples from the latter company came from their own kilns and from various parts of the United States but were hydrated on their American hydrating machine.—G. P. G.

cent. difference could be detected at any time in the eight weeks between cold water, hot water, and steam hydration, though the hot water seemed to give somewhat better results than cold.

	Tensile strength.
With cold water—average 6 briquettes.....	55 pounds.
With hot water—average 6 briquettes.....	66 “
With steam—average 6 briquettes.....	66 “

Such slight differences indicate little or no advantage in one method over another.

The addition of sulphuric acid and hydrochloric acid to the slaking lime gave a different effect to the addition of these acids to the mortar at the time of molding the briquettes.

	Tensile strength.
2 per cent. sulphuric acid to the slaking lime.....	57 pounds.
5 per cent of sulphuric acid to the slaking lime.....	97 “
5 per cent. of hydrochloric acid to the slaking lime.....	88 “

The advantages of hydrated lime are:

1. Permanent bulk, which permits the use of a convenient package with no danger of loss.
2. No danger of fire.
3. The use of a dry powder is usually more convenient than that of a wet paste.
4. Less time is required for seasoning for use as mortar as there are no lumps to be reduced.
5. The increase in weight due to water added is probably balanced by the removal of the underburned and overburned stone, if the hydration is carried out properly.

One point of scientific interest has been noted in connection with the study of air slaking limes. Two old thoroughly slaked samples of lime were observed to have varying amounts of carbonic dioxide and it was found that the higher carbonation occurred in a dolomitic lime. From an inspection of all our tests, a slight tendency is found toward a greater absorption of carbonic dioxide by a magnesian lime. The average absorption in the several samples after two weeks' exposure while the absorption was rapid is shown below:

High calcium limes.....	16 per cent.
7 to 10 per cent. magnesian limes.....	19 “ “
Dolomite limes.....	22 “ “

If further tests along this line should confirm this indication found in the 15 or 20 samples tested, it might lead to an explanation of the differences between the strength of magnesian and other limes. Possibly the initial superiority of high calcium limes

is due to their greater hydration and that the strength is due more to the drying of the hydrate than to carbonation. On the other hand, magnesian limes at first are weak, but after long standing are superior in strength. Although the process of carbonation of mortar is slower than that of a loose powdered lime, I would suggest that the greater ultimate strength of dolomitic limes may be due to greater absorption of carbonic dioxide.

The amount of carbonic dioxide has also been determined in some of the plaster briquettes which have been exposed for three months, and some old plasters used on some of the oldest buildings in the State. It is evident from these determinations that carbonation is much slower in a mortar than in the samples of lime exposed to air slaking in comparatively thin layers.

OLD LIMES FROM BUILDINGS.

	1.	2.
Lime oxide.....	9.5	8.8
Magnesium oxide.....	0.05	0.48
Carbonic dioxide.....	7.90	7.16
Carbonic dioxide (theoretical).....	8.60	7.40

LIMES EXPOSED THREE MONTHS.¹

	1.	2.
Lime oxide.....	13.7	15.0
Magnesium oxide.....	1.29	0.29
Carbonic dioxide.....	12.20	6.21
Carbonic dioxide (theoretical).....	12.30	12.00

Fungicides and Insecticides.

Lime is mixed with iron sulphate, often called copperas, and water to form a spray under the name of *Bordeaux mixture*. This compound is useful in destroying fungus growths on vines and trees.

Lime and sulphur heated to high temperature unite, forming a group of lime sulphides which have been extensively used in orchards and vineyards in destroying scales and other insects. Fifty gallons of water are used with 15 to 40 pounds of lime, 15 to 20 pounds of sulphur and about 15 pounds of salt. The mixture is boiled before use and does not injure the trees even when used in excess at any time of year.

1. End of Mr. Grout's paper.

Lime on Soils.

Lime was for many years regarded as a most valuable fertilizer on soils in a direct action on vegetation. The ash of plants was chemically examined and it was found that lime formed one of the common elements, and the value of lime on soils was supposed to be due to the supply of this element to the growing plant. The soil, however, will in nearly all cases contain enough lime to supply the amount required as food by the plants, and it would be an exceptional case where the soil would require lime for this purpose. If the lime had no other use on the soil, its value for agricultural purposes would be little or nothing, but fortunately it serves other and valuable functions which will be considered under two heads, chemical and mechanical.

Chemical Effects of Lime on Soil.—There exist in soils various chemical compounds which contain elements necessary for the growth of the plant. As long as these elements are included in the compounds they are not available for use. The compounds may be broken down slowly by weathering action and by decaying vegetation with its resulting acids. Lime is found to be a useful substance in breaking down many of these compounds, especially the groups of hydrous soluble silicates and salts of humous acids, whereby potash is liberated. Lime thus indirectly aids in the supply of food for the plants.

Dr. Wm. Frear in his exhaustive report on agricultural use of lime in Pennsylvania¹ speaks of the value of lime to prevent the formation of incrustation caused by the excessive use of soluble fertilizers, and also its use in correcting the harmful influence of ferrous salts in the soil.

Sulphides in the soil sometimes oxidize and form sulphuric acid and ferrous sulphates, also a large proportion of decomposing organic matter will reduce ferrous sulphate and the sulphate of lime, which result in *acid soils* with low degree of productiveness. Many so-called exhausted soils are acid soils which may have the necessary constituents for a fertile soil, but have this injurious acid character in addition. Improperly prepared phosphate fertilizers sometimes are to blame for this acid condition. Lime oxide (quick lime) or lime carbonate neutralizes the free

1. Report of Depart. of Agriculture, 1900. This valuable memoir has been freely used in this discussion of lime on soils.

acid of the soil and decomposes ferrous salts to harmless compounds, while iron sulphide (pyrites) is converted into non-injurious ferric oxide and lime sulphate.

The lowland soils, according to Dr. Frear, usually have a good supply of lime brought in solution from the hills and slopes to the valley, and acid soils are rarely found in such sections. The upland soils, subjected to the leaching action of circulating waters and if formed from rocks with low percentage of lime, are very apt to be poor in lime and acid in character.

In order to correct this acid character, pure lime may be used, the carbonate, or a magnesian lime. Caustic lime is regarded as better than the carbonate in that the action is stronger and more rapid, it also decomposes organic matter better and works as an insecticide and fungicide. Twice as much carbonate would be required as oxide. Magnesian limes were found by the Pennsylvania experiments to affect organic matter as well as pure lime, and that a smaller amount was required to correct the acidity. It should be used in moderate quantity so as not to render the soil too highly alkaline.

In some sections, as in eastern part of West Virginia, it is customary for the lime companies to use the better grades of rock for building lime, and to use the poorer grades for agricultural lime which thus has a higher percentage of impurities. This lime is sold at a lower price to the farmers, and if properly burned is good. If sold at the same price as pure lime it would be more expensive as the farmer would pay for the impurities which would be useless on the soil.

According to information furnished by the Agricultural Experiment Station, acid soils are not uncommon in certain sections of this State, and the cause of trouble is often unknown to the farmer who begins to use various patent fertilizers with poor results. With the abundance of limestone, agricultural lime should be obtained at reasonable prices in most sections and there should be no acid soils.

There appears to be a difference of opinion whether the lime should be used in a slaked or unslaked form. It is argued by experienced soil chemists that the slaking of the lime in the soil gives increased benefits. If slaked and dried it is more easily drilled into the soil. The unslaked lime must be ground for this purpose, and if shipped in this ground condition will rapidly air

slake. The hydrated lime is now extensively sold for agricultural use.

Mechanical Effects of Lime on Soil.—Lime also exerts an important mechanical influence on soils. On loose soils, the lime is known to flocculate the soils; that is, collects together the loose particles and so makes the soil more granular. This may be illustrated by placing lime in a muddy liquid and the mud will flocculate and settle to the bottom leaving the liquid clear. The excessive use of lime may render the soil hard and compact.

Lime also has an opposite effect on tough clay soils where it granulates them, breaking the soil up into finer particles, rendering it porous. An additional explanation for this change is given by the chief chemist of the Survey, B. H. Hite,¹ who states that the lime shrinks less than the films of clay surrounding the lime particles, which are warped and cracked in drying thus opening the texture of the clay.

Lime was formerly used to a large extent as fertilizer on land with the erroneous theory that it served as food for the growing crop. The extensive use accelerated the breaking down of the compounds in the soil giving great increase in crops but hastening the exhaustion of the soil. When the soil was found to be practically exhausted in the various elements required by the plants it no longer yielded to the lime application. Lime was then looked upon as injurious to soil and its popularity decreased. Farmers are now learning its proper functions in the soil and recognizing its great value when properly used on soils which need its application. There is a growing demand for lime not as a fertilizer so much as a modifier or curative of so-called sick soils. The use of lime on soils in West Virginia is said to be small, while the need of lime on the soils of many sections is said to be great. This subject demands the most careful study of every farmer.

Lime Hydrate.

The method of preparing hydrated lime for the market is described in another chapter of this report, but in this place it may be well to consider some of the special uses of lime hydrate and the claims made for it. The preparation of a hydrated or ready

1. W. Va. Agricult. Exper. Station, Bull. 80, p. 342.

slaked lime to be sold by the lime manufacturer to the consumer ready for immediate use is a recent feature of the lime industry so that it is sometimes called the New Process Lime, etc.

The advantages claimed for lime hydrate are set forth as follows in a recent catalogue advertising lime hydrating machinery:

1. It has great advantage over quick lime in its keeping quality as it does not deteriorate with age, and there is no loss through air slaking.

2. It is permanent in bulk, having passed through its expansive stages, and can therefore be placed in paper or any other package without danger of rupturing the same.

3. If properly made, it retains its strength and plasticity.

4. When all the impurities in the quick lime are rejected by this process, this labor is saved the user.

5. Since it contains no impurities, the purchaser is buying pure lime, and not an unknown quantity of worthless matter.

6. There is a saving in storage, handling, packing, and freights through the rejection of all waste in advance.

7. The hydrated lime is ready for immediate use, no slaking or seasoning necessary.

8. It can be mixed dry with sand, gypsum, plaster, or cement, and a more intimate mixture made with much less labor.

9. When mixed with sand, a relatively smaller quantity need therefore be used to make a mortar of the same strength.

Conclusion.—It is reasonable to suppose that eventually all lime will be put on the market in this finished condition, except when needed for its caustic properties.

If all the above claims are true, it certainly would be only a short time until nearly all manufacturing lime companies would be forced to add hydrating plants, and the demand for hydrated lime is certainly increasing very rapidly. One large eastern company is now selling 1,000 barrels daily of hydrated lime and the new equipment for this work is being installed in all parts of the country. Practical workmen who have used both quick lime and the hydrate in most cases recommend the hydrate, so it must be an important step in the progress of the lime industry even if it does not accord with all the claims made for it. The claims made above for the superior quality of the hydrate while taken from one catalogue are generally accepted by the hydrate lime manufacturers, and these claims may be briefly examined.

The first claim that hydrate lime does not deteriorate with age and does not air slake would be true if kept in a dry place. In dry air the hydrate and the quick lime, air slake very slowly. Air slaking is due to the absorption of carbonic acid gas from the at-

mosphere, converting the lime to a carbonate. Quick lime and the hydrate undergo this change which takes place in moist air more rapidly than in dry. Quick lime exposed to the air also absorbs moisture and crumbles to a powder, popularly called air slaking, and such lime has sometimes been regarded as worthless, but tests made on such air slaked lime have given good results. If only water is absorbed, such air slaked lime would be a hydrate and just as valuable as hydrate lime, but with time there is also the absorption of the carbonic dioxide which injures the strength of the lime, but the lime hydrate would also absorb this carbonic dioxide or carbonic acid gas as it is called.

The second claim is certainly true and represents one of the great advantages of lime hydrate, avoiding the trouble and expense of barrels, which cost from 15 to 25 cents each. There is also the important advantage of avoiding danger of fires when the lime is accidentally exposed to water. Some very disastrous fires have resulted from quick lime brought in contact with water. If hydrated lime was in all other respects merely the equal of quick lime, these two advantages ought to establish the industry in this country.

The third claim is in reality a repetition of the first. In the fourth claim with good commercial quick limes, the waste material would consist of unslaked and underburned lumps which are usually separated in passing through the screen in the lime slaking box, so the labor saving would not be very large. Of more importance is the fact that small underburned and unslaked pieces in the quick lime process are apt to pass through and cause later trouble on the wall or in the masonry by slaking, causing blistering or popping of the wall. With a good process of hydrate lime this trouble would be avoided.

The fifth and sixth claims in part, should not be emphasized by the manufacturer, since in the process of hydration 56 pounds of lime take up 18 pounds of water, which latter ingredient sells for the same price as the lime content and would more than offset the weight of the waste products in a first grade commercial quick lime.

The seventh and eighth claims are true and represent important advantages of the hydrate lime. The seventh claim is especially important when the plasterer or mason has to employ cheap and inexperienced labor for his work of slaking with the result

often of a mixture lacking in uniformity. The saving in labor and trouble here will in most cases balance the cost of the added water in the hydrate lime.

The differences mentioned in the ninth claim would be very small if the trouble mentioned in the preceding paragraph was avoided, or in other words if the quick lime was thoroughly and uniformly slaked.

While lime hydrate does not fulfill all the claims made above for it, it possesses enough of them to render the process an important one and it certainly represents marked progress in the lime industry, and with the recent improvements in the process and the growing demand of the market for this lime the conclusion from the claims given above seems indeed reasonable.

Special Uses of Hydrate Lime.

The main use of hydrated lime is for mortar, and when a good process is carefully used insures a uniform plaster. This lime is also used in a number of special lines of work which will be briefly described.

Sand Lime Brick.—In the manufacture of sand-lime brick, lime and sand form the mixture, but the lime must first be hydrated and the product must be uniform and thoroughly hydrated. The lime may be hydrated at the plant, but the purchase of a good lime hydrate saves the trouble of hydration at the plant and saves time, with the certainty of securing a correct hydrate if a good brand is used.

Hard Wall Plaster.—In those parts of the country where gypsum hard wall plasters can be economically used, the lime industry has been on the decline. The hard wall plasters, possessing certain advantages of fire proof character, resistance to injury by water, durability under jar, have displaced lime plaster to a considerable extent. Such hard plasters set quickly, are difficult to spread and float, and act as sounding boards. A mixture of the hard plaster and hydrate lime overcomes the objections to hard wall plaster and is claimed to retain its advantages. The mixture is made differently by different workmen and ranges from 10 to 50 per cent. of lime hydrate. This is a new phase of the lime industry and not enough data have accumulated to give

an opinion on the value of this mixture, but it is a promising field for trial and experiment.

Portland Cement Mortar.—When Portland cement mortar is used in stone and brick work, it is found to work under the trowel much more easily when lime putty is added. Hydrated lime is especially adapted to this work, as it can be mixed dry with the cement and give an intimate mixture.

The following table shows the strength of Portland cement, sand, and hydrated lime mixtures:¹

Test No.	Time and Pounds Pressure per Square Inch.			
	3 Mos.	6 Mos.	9 Mos.	12 Mos.
1.....	340	750	785	585
2.....	360	557	530	540
3.....	272	455	520	442
4.....	135	268	300	280
5.....	60	257	295	310
6.....	107	268	268	263
7.....	123	145	193	185

1 was a mixture of one part Portland, two sand, one-fourth part lime.

2 was a mixture of one part Portland, three sand, one-half part lime.

3 was a mixture of one part Portland, four sand, three-fourths part lime.

4 was a mixture of one part Portland, five sand, one part lime.

5 was a mixture of one part Portland, six sand, one and one-fourth lime.

6 was a mixture of one part Portland, eight sand, one and one-half lime.

7 was a mixture of one part Portland, ten sand, two parts lime.

Concrete.—The mixture of Portland cement and broken stone forming concrete, makes a porous compound and not water proof. In foundations, cellar walls, etc., it is an advantage to have the construction as nearly water proof as possible. The mixture of hydrated lime with the concrete makes the concrete more nearly water proof. Ten to twenty-five parts of hydrated lime are used with one hundred parts of Portland cement. Lime hydrate is now being used in the concrete for the new Washington terminal station, and has been used to advantage in other structures. It is also recommended for use with the cement in the manufacture of concrete building blocks, where it is claimed to improve the moisture resisting properties and to produce a lighter shade in the blocks.

1. E. W. Lazell, *Rock Products*, Vol. IV., No. 4, p. 35.

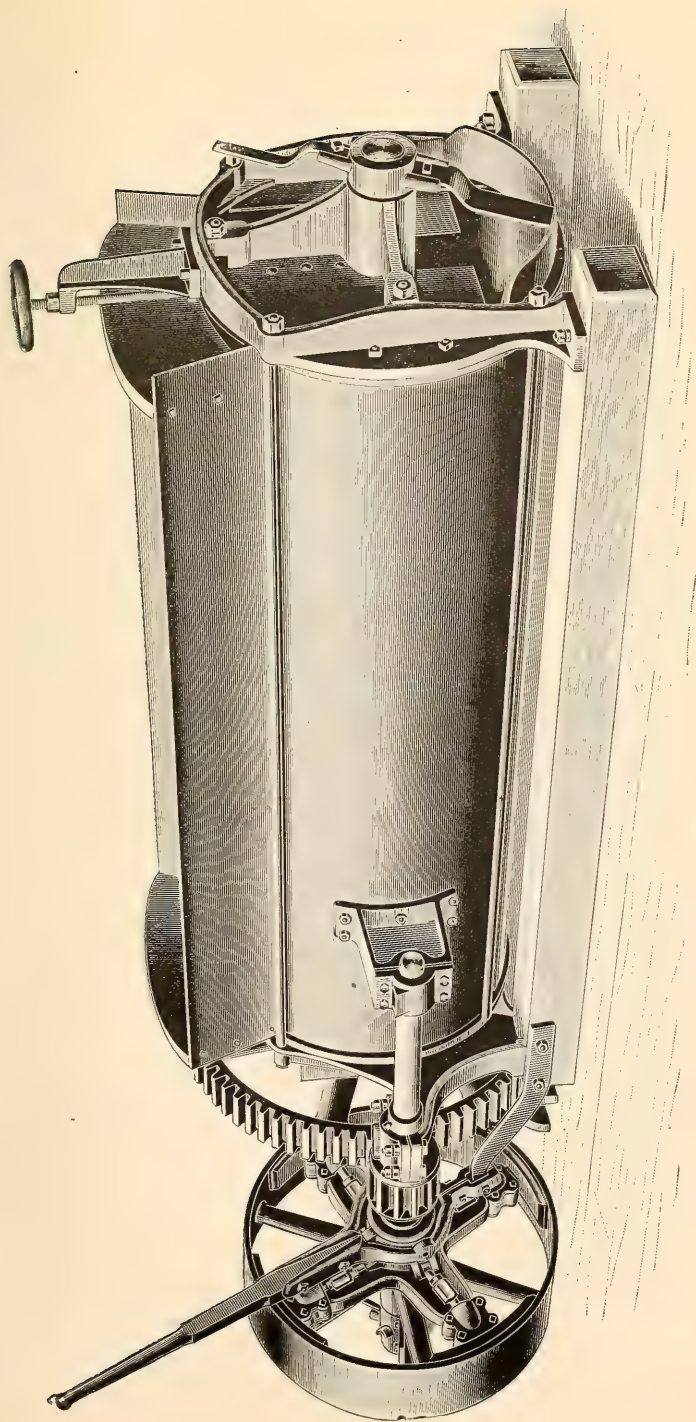


Plate IV.—American Clay Pug Mill.

Insecticide.¹—Hydrated lime is mixed with kerosene to form a spray. Four pounds of the hydrate absorb one gallon of kerosene, and the two materials in combination are said to mix very readily with water. For special uses this mixture may be combined with Bordeaux mixture, with Paris green, or with copper sulphate. The mixtures are made in 10 and 15 per cent. strengths for summer applications and in 20 and 25 per cent. strengths for winter and early spring use.

Use of Lime Chloride With Lime in Plaster.²

Mr. Thomas W. Cappon, of New York city, has been granted a patent on a mixture of lime chloride and lime to form a hard wall plaster.

Formula 1 calls for one gram lime chloride to 21 grams of hydrated dolomitic lime, or 4.76 per cent.

Formula 2 uses 21 grams of the hydrated dolomitic lime and 4.5 cubic centimeters of 22 per cent. solution of lime chloride, or 5.65 per cent.

Formula 3 uses the same weight of lime and 4.6 cubic centimeters of the same solution of lime chloride, or 5.78 per cent.

A series of experiments were made by Mr. Cappon with the third formula on Buckeye lime from Genoa, Ohio, made from a limestone with the following composition:

Lime carbonate.....	58.44
Magnesium carbonate.....	39.45
Silica	0.12
Iron and alumina.....	0.26
Lime sulphate.....	0.26
Loss on ignition.....	1.56

The lime from this rock was hydrated and analyzed showing the following percentages of the components:

Lime hydrate.....	50.28
Magnesium hydrate.....	42.43
Lime carbonate.....	4.43
Iron and alumina.....	0.14
Silica	0.05
Water in excess.....	2.51

Three equal amounts of the ground unhydrated lime were taken and the same quantity of lime chloride solution containing 22.2 per cent. was added to each with different amounts of water

1. Data furnished by Chas. Warner Co., Wilmington, Delaware.

2. The data in this section were taken from a private report of Mr. Cappon loaned to the writer.

as follows: First sample, enough water for hydration; second sample, 25 per cent. excess of water; third sample, 50 per cent. excess of water. The solution was thoroughly stirred and when cold was ground to pass a 40-mesh sieve. One hundred and fifty grams of the lime chloride mixture were mixed with 900 grams of sand and 150 c. c. of water. The three samples were made into briquettes which were broken in 42 hours and showed the following tensile strength per square inch:

First sample.	Second sample.	Third sample.	Without lime chloride.
93	87	111	26
71	81	95	26
89	87	88	27
90	77	87	26
95	87	104	26
..	..	79	..
Average.91.7	85.4	87.2	26.2

Mr. Cappon gives four methods for making the mixtures and recommends especially the fourth.

1. Add the desired amount of lime chloride in the form of a solution to the ground lime during the process of hydration. This method was used in the above tests.

Its chief objections are, first, the care required to handle large quantities of lime owing to the great amount of heat developed during hydration. It is necessary to grind the lime before slaking and to stir continually during the addition of water and lime chloride liquor. A subsequent grinding and screening are also necessary. Second, there is a strong trade prejudice against lime hydrated by other than the wet process. The success of the method would depend on carrying the hydration as near completeness as possible and still keep the product dry and also with the degree of fineness obtained in the final grinding and screening.

2. Add the required amount of lime chloride in solution to the thoroughly hydrated dolomitic lime at the time the plaster is mixed for use. Experiments gave by this method an average tensile strength of 53.4 and 55.6 pounds. The disadvantages of the method are the shipping of lime chloride in liquid form, the making up of small lots of the material, and the risk of poor mixing when laborers without special training are employed.

3. This method is a modification of the first and aims to retain the advantages of adding lime chloride during the hydra-

tion of the lime, and at the same time diminish the difficulties connected with this method. Strong solutions of lime chloride are used in the hydration of the dolomitic lime. After grinding and screening this mixture a small amount is taken and mixed with a large quantity of thoroughly hydrated lime. In this process the tensile strength averaged 75 and 78 pounds.

4. Mix the desired amount of powdered lime chloride with dry, thoroughly hydrated lime, and screen the product. This method is especially recommended by Mr. Cappon, as it is simple and leaves the manufacturer free to choose his own method of slaking, the only requirement being that the product must be perfectly dry and fine. The average tensile strength is 59 to 63 pounds.

For comparison the average tensile strengths in pounds per square inch of the plaster after 42 hours are brought together, the numbers referring to the methods outlined above.

No	Method 1.	Method 2.	Method 3.	Method 4.
Lime chloride.				
26.2	87.2 to 91.7	53.4 to 55.2	75 to 78	59 to 63

While the fourth method is more simple and easier to apply, the plaster does not reach the strength of the third and first methods. In all these methods the plaster is claimed to show no traces of cracking or popping and the strength of plaster by any of the methods is over double that of lime without addition of lime chloride.

Minor Uses of Lime.

Lubricant.—A very fine flaky variety of lime mixed with oil is used as a lubricant in some manufacturing plants of Ohio. *A boiler covering*¹ is made from a mixture of mica, sodium silicate, lead acetate, and lime. *Cement Paint.*¹—A cement paint is made with the following composition :

White lead.....	50	parts.
Litharge	25	"
Varnish	6	"
Bone glue.....	15	"
Turpentine	5	"
Silicate of potash.....	5	"
Dryer	20	"
Lime	30	"
Water	44	"

1. Rock Products, Vol. II., No. 12, p. 23.

Lime Light.—Pencils made of lime are used in the oxy-hydrogen flame to give an intense white flame in the stereopticon.

Disinfectant.—Lime on account of its absorptive properties is valuable around the house, stables, etc., to take up offensive odors. The bleaching powder wrongly called lime chloride is a valuable disinfectant.

Milk of Lime.—Lime is slaked in an excess of water to form a milky solution used in the distillation of ammonia and other processes.

Lime Cartridges.—In coal mines, especially where fire damp is prevalent, lime cartridges have been used.¹ These are made by compressing quick lime into cylinders leaving a small hole down the middle. They are put into drill holes and tamped with sand. Water is poured into the hole and passing into the perforated cylinder, wets the lime, which swells on slaking, and exerts great pressure. The coal is broken down without any flame or concussion, with no danger from the gas.

Pottery Glaze.—According to Ries, lime is used in the manufacture of the pottery body and as a constituent of the glaze in some potteries.

Dolomite Lime Paint.—In Germany, experiments claimed to be successful, have been made on the use of dolomitic lime as a substitute for white lead in paint. The limestone should have 20 per cent. of magnesium carbonate. The calcined lime is mixed with a hydro-carbon and heated until all the carbon is consumed. The claims made for this paint are, its fineness and smoothness of surface, covering power, permanence and cheapness, quick drying qualities without the addition of drier, freedom from turning yellow with age, unaffected by ammonia, sulphuretted hydrogen, or sulphurous acid, a natural hardening and enamelling after a few months, can be washed without injury to its smoothness, and coloring pigments may be used with it as readily as with white lead.

1. Thorp, *Outlines of Industrial Chemistry*, p. 432.

CHAPTER XVII.

THE CLASSIFICATION, HISTORY, AND COMPOSITION OF CEMENTS.

CLASSIFICATION OF CEMENTS.

1. Natural hydraulic limes.
2. Natural hydraulic cements.
3. Portland cement.
4. Puzzolane cement.
5. Slag cement.

When ordinary limestone is burned or calcined it forms lime, a valuable product in the building trades, but which will not set under water, or when set and placed under water will disintegrate. It would be useless for hydraulic purposes.

Certain impure limestones when burned form a product which can be used under water, and therefore have hydraulic properties. If this calcined product slakes to a powder on exposure to the air, the material is called *hydraulic lime*. If it burns to a clinker which must be ground to a fine powder before use, the material is called *hydraulic cement*. The two products depend upon a difference in the amount of impurities in the limestone. If the percentage of silica and alumina in the lime rock is below 20 or 25, the calcined product will slake.

Portland cement is an artificial mixture of lime, silica, and alumina burned at high temperature and the resulting clinker ground to a very fine powder. The proportion of ingredients must be carefully determined, thoroughly mixed, properly burned and finely ground.

Puzzolane cement was originally made from cinder-like volcanic fragments found in large quantity at Pozzuoli near Naples, Italy, and used from ancient times. The material is reddish brown to gray in color, insoluble in water and consists of silica, alumina, with small quantity of potash, soda, and iron oxide.

When mixed in uncalcined state with rich limes and ground it becomes hydraulic, the soluble silicic acid combining with the lime. The mixture varies in different places but is about one part of lime to one of sand and one of puzzolane. It is found in nearly all volcanic regions, and some varieties are improved by slight calcining. Along the valley of the Rhine a similar material called *trass* has been used in the same way.

Slag or puzzolane cement in later times has been made by mixing lime with granulated blast furnace slag, ground together without burning. The slag may also be mixed with limestone, ground and burned together, forming a true Portland cement, sometimes described as slag cement, but not to be confused with the puzzolane slag cement.

HISTORY OF THE CEMENT INDUSTRY.

Hydraulic limes are rarely used in this country but are important in some parts of Europe. Hydraulic cements were known and used by the ancient Egyptians and Romans, but the great development of the cement industry was during the nineteenth century, especially in the latter portion of it.

The first recorded authentic experiments on the use of hydraulic cement were made by John Smeaton in 1756 in building the Eddystone lighthouse, and the first patent on cement was taken out in 1796 by Parker in England for a Roman cement which was in reality a natural rock cement made from septaria lime nodules.

In 1818 Vicat published in France an account of hydraulic lime made from a mixture of chalk and clay, and in 1822 Frost took out a patent in England for this mixture under the name of hydraulic lime. In 1824 John Apsdin secured an English patent for a cement made from the same mixture of chalk and clay, which he named Portland cement because of its resemblance when set to the well known building stone quarried at Portland Neck, seen in Westminster Abbey, and other prominent structures. Thirty years later there were four factories in England making a cement of inferior quality. In the 70's the industry had become fairly well established and English cement was exported to the markets of the world. Most of the cement in England is made

from a mixture of chalk and the Gault clay in the lower Thames and Medway valleys.

The Portland cement industry started in France about 1850, in Germany in 1855, and in Belgium in 1872. The cement works of North Germany use chalk and clay as in England, but in the central part marl and clay are used. The Dyckerhoff and Mannheim works use a hard limestone and clay. Germany is the great Portland cement center of the world and supplies over half of the cement imported to the United States.

The first Portland cement mill in this country was built at Coplay, Lehigh county, Pennsylvania, in 1872. In the next eight years the total production was 82,000 barrels. In 1890 the production was 335,000 barrels from sixteen factories, and in 1900, 8,482,000; in 1903, 22,342,973 barrels from seventy-eight factories, with over 2,000,000 barrels imported. Pennsylvania produces 43 per cent of the total. Three-fourths of total production comes from Pennsylvania, New Jersey, New York, Michigan and Ohio.

Natural Hydraulic Cement was patented in England under the name Roman cement in 1796. It was made in 1842 in France. The impure limestone adapted to this kind of cement is not uncommon, but is widely distributed, but such stone is apt to vary in quality in the same quarry or even in the same layer. There are comparatively few localities known where large deposits of natural cement rock uniform in quality can be found.

In making the preliminary survey and soundings for the Erie canal in 1818, the engineer, Canvas White, discovered the natural cement rock at Chittenango, Madison county, New York, and erected a plant at this place where most of the cement for the canal was made.

In 1825 in the construction of the Delaware and Hudson canal, the deposits of Ulster county were discovered and the Rosendale cement industry was started one year later. In 1830 the stone was floated down in canal boats to Newark, New Jersey, where it was burned into cement until 1849, when the works were moved to Kingston. New York has 20 natural cement mills with production of about 2,500,000 barrels.

The plant at Shepherdstown, West Virginia, was started in 1827, and at Louisville, Kentucky, in 1829 for use on the Louisville and Portland canal around the Falls of the Ohio. The second mill at Louisville was erected in 1854. There are at the present

time 18 cement mills in the Louisville district with annual production of 2,000,000 barrels.

A ten-barrel natural cement mill was erected near Fort Scott, Kansas, in 1868, and increased to 350 barrels in 1888. At the present time there are two mills with a daily capacity of 1,500 barrels.

The demand for natural cement has been decreasing in the past few years, being replaced by Portland. A number of the plants are being reconstructed into Portland mills, and others have been idle. The United States leads the world in the production of natural cement.

THE COMPOSITION OF CEMENTS.

Natural Cement.

A natural cement rock is a limestone containing 18 to 40 per cent. of silica and alumina with a small percentage of alkalis. It often contains a considerable percentage of magnesia, from 3 to 35 per cent., but this appears to be inert as far as the cementing properties are concerned. Natural cements are not injured by the high magnesian percentage as are Portland cements.

The composition of a few well known natural cement limestones are given in the following table:¹

	Cumberland, Md.	Shepherdstown, W. Va.	Ulster Co., N. Y.	Hancock, Md.
Carbonate of lime....	41.80	58.25	30.72	65.0
Carbonate of magnesia	8.60	11.16	35.10	5.3
Silica	24.74	17.84	19.64	27.1
Alumina	16.74	4.60	7.52	1.5
Oxide of iron.....	6.30	1.70	2.38	
Alkalies	6.18	not det.	4.10	0.3

In burning the rock, the carbonic dioxide (CO_2) is removed, and the lime combines with silica and alumina, forming silicates and aluminates. The analyses of the natural cements are given below.²

	Rosendale, N. Y.	Louisville, Ky.	Cumberland, Md.	Lehigh Valley, Pa.
Lime	34.54	41.80	49.60	53.50
Magnesia	21.85	16.29	3.76	2.40
Silica	22.73	24.40	28.30	26.50
Iron and alumina oxides	10.43	6.20	14.54	11.40
Alkalies	3.63	1.52	....	....
Water, CO_2 and loss ....	....	9.89	....	....

1. Gillmore, Limes, Hydraulic Cements and Mortars, p. 125.

2. Ohio Geol. Survey, Vol. VI., p. 674, Lord; Min. Industry, Vol. VI., p. 96.

Natural cement rock is burned at a temperature of about 900° C. usually in stone or iron kilns similar to those used for lime. The resulting clinker is readily ground to a flour, being softer than Portland cement clinker.

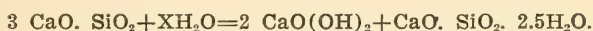
The American cements are quick setting, reaching a set in less than one-half hour, and have a tensile strength in seven days (without sand) of 60 to 100 pounds to the square inch, while Portland cement reaches 250 to 500 pounds. The specific gravity of natural cement is somewhat lower than Portland.

PORTLAND CEMENT.

Portland cement is formed from a definite mixture of lime, silica and alumina, burned to a slag-like clinker and ground to a fine powder.

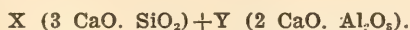
The chemical composition of this cement has been a problem of investigation for the past twenty-five years, and has involved the skill of some of the most eminent chemists of the world.

In 1887 the French chemist, Chatelier,¹ after careful synthetic determination gave the formula for Portland cement as $x (3 \text{ CaO. SiO}_2) + y (\text{CaO. Al}_2 \text{ O}_3)$, in which x and y are variable quantities depending on the relative proportion of silica and alumina in the clay used. The lime silicate was regarded as the basis of the hydraulic activity, and on hardening shows the following reaction:



and consisted of hexagonal crystals of lime hydrate surrounded by a white mass of needle-shaped hydrous non-calcium silicate.

The work of S. B. and W. B. Newberry in this country showed that better results could be obtained by a modification of this formula to



or two molecules of lime to one of alumina instead of three molecules of lime as in the Chatelier formula.²

Substituting weights for chemical equivalents gives

$$\text{Lime} = \text{Silica} \times 2.8 + \text{alumina} \times 1.1.$$

or using carbonate of lime instead of the oxide Newberry gives

1. Ann. des Mines, p. 345, 1887, quoted Ohio Geol. Survey, Bull. 3, p. 206, 1904.

2. The Cement Industry Eng. Record, p. 14.

the rule of mixture for maximum amount of lime carbonate to be used:

Five times the percentage of silica plus twice the percentage of alumina equals the number of parts of lime carbonate required for 100 parts of clay.

The impurities, magnesia and iron, in the clay are to be disregarded. The lime impurity in the clay can be calculated as lime carbonate and subtracted from the estimated amount required according to the formula.

Bleininger¹ from his experiments on the Ohio survey regarded the safest formula for dry ground mixtures to be



or by weight one part silica to 2.61 parts of lime, or 4.66 parts of lime carbonate. The above rule of mixture would be modified by changing five times the percentage of silica to 4.66 times.

The application of this rule² may be illustrated by a practical example, using some West Virginia materials as found near Martinsburg.

The shale has the following composition,

Silica	56.67	per cent.
Alumina and iron.....	26.58	" "
Lime oxide.....	2.23	" "
Magnesium oxide.....	1.94	" "
Alkalies	4.04	" "

and the limestone:

Lime carbonate.....	96.82	per cent.
Magnesium carbonate.....	1.29	" "
Silica	0.69	" "
Alumina and iron.....	0.62	" "

The shale would require according to the rule,

$$\begin{aligned} 56.67 \times 4.66 &= 264.0 \text{ parts} \\ 26.58 \times 2.00 &= 53.1 \text{ "} \end{aligned}$$

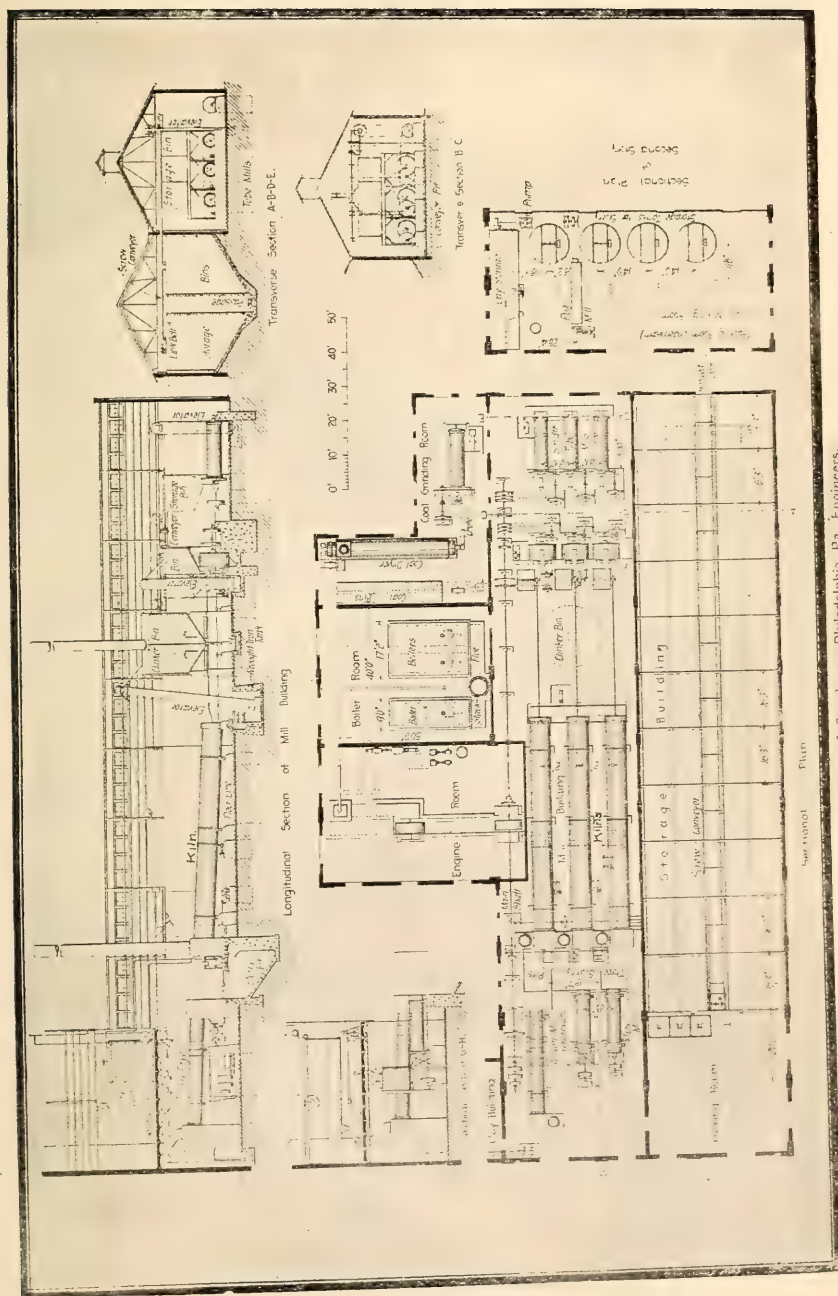
317.1 parts lime carbonate.

The shale contains 2.23 per cent. of lime oxide which must be deducted as lime carbonate, thus giving

$$317.1 - (2.23 \times 100 \div 56) = 313.1 \text{ parts of lime carbonate required.}$$

1. Geol. Survey of Ohio, series 4, Bull. 3, p. 236; 1904.

2. Credit for the application is due Bleininger loc. cit., p. 239.



Lathbury & Spackman, Philadelphia, Pa., Engineers.

No. 1.
Plate XXXII.—Plan of a Modern Three Kiln Portland Cement Mill.

The limestone contains silica and alumina which will combine with part of lime present so the amount of lime really available will be

$$96.82 - (0.69 \times 4.66 + 0.62 \times 2) = 92.37 \text{ per cent. of lime carbonate.}$$

The amount of limestone to be used for one part of shale is therefore $313.1 \div 92.37 = 3.389$ parts or 100 parts of shale require 339 parts of limestone.

CHEMICAL CONSTITUENTS OF PORTLAND CEMENT.

The following table as given by Lathbury and Spackman,¹ cement engineers, shows the practical range of ingredients in Portland cement mixtures:

	Minimum. per cent.	Maximum. per cent.
Silica	19	26
Alumina	4	10
Iron	2	5
Lime	58	67
Magnesia	0	5
Sulphuric acid.....	0	2.5
Alkalies	0	2.8

Silica, alumina and lime are the essential components, with fluxing elements to lower the temperature of fusion.

Silica occurs in rocks in three forms, crystalline, amorphous, and in combination in form of silicates.

The crystalline variety is known as quartz, colorless and transparent when pure, specific gravity of 2.65, almost insoluble and infusible, but in the presence of carbonic acid formed by decomposing carbonates, it may form silicates with the bases of the carbonates, and then becomes soluble in water.

Quartz occurs in large and small crystals or rounded grains of varying size. According to the experiments of Bleininger, quartz grains with a diameter of over .005 inch are practically inert in the hydraulic cement mixtures, as they will not unite with the fluxing elements to form a fusible silicate.

Amorphous silica occurs in nature in the form of opal and chalcedony and differs from quartz in its chemical composition by containing water. It is also formed from the alteration of quartz or silicate minerals, as colloidal silicic acid which is an active

1. Rock Products, Vol. I., No. 7, p. 10.

agent in cement formation, its chemical energy, according to the above mentioned author, increasing with increase in amount of its chemically combined water.

Silica also occurs in the form of silicates of various bases, forming a large series of minerals found in igneous rocks.

Alumina is a common element in the rocks of the earth, forming a large portion of the composition of pure clay. In its purest form it is united with oxygen forming such substances as ruby, corundum and mixed with iron forms emery. This element also combines with bases forming aluminates.

Lime silicate is regarded as the basis of the hydraulic properties of cement, but by itself it has no cementing properties as shown by Bleining in numerous experiments.

A pure clay having high percentage of alumina mixed with lime forms a hydraulic cement, but with rapid set. For a practical cement mixture there must be lime silicate with alumina present. If the latter is present in considerable quantity the resulting aluminous cement will have too rapid a set and this must be counteracted.

Iron oxide is present in nearly all rocks and gives the color to many of these. Too high a percentage appears to be injurious in cements where its influence is mainly as a fluxing agent, thus lowering the temperature required for burning the cement.

Iron may be present in the form of sulphide or pyrites and then may prove injurious on account of the sulphur brought into the cement.

Lime is the largest constituent in cement and is the base of the silicate and aluminate composing the cement. It readily unites with silica and alumina under elevated temperatures, and the action is accelerated by the presence of silica and alumina impurities in the limestone.

Magnesia is found in varying proportions in nearly all limestones, and has long been considered as injurious in the manufacture of Portland cements, and has even been cited as representing the difference between natural cement rocks and those adapted to Portland cement. More recent investigations show that its presence in natural cement rocks is not essential, but accidental.

According to Newberry, magnesia shows no hydraulic properties when heated with silica and alumina and is to be regarded as inert when present in small proportions. Other investigators

have maintained that magnesia unites with the silica and alumina giving hydraulic properties and may even take place of part of the lime with good results. While the problem is not definitely settled there seems to be a rather general agreement that magnesia over 5 per cent. is apt to be dangerous to the quality of the cement and especially to its weather resisting properties.

Alkalies as soda and potash are usually present, especially in the clays or shales used. They have been regarded by some investigators as important fluxes to bring about the union of lime with silica and alumina at lower temperature, but according to Newberry they have no such influence and are to be regarded as inert in the cement formation.

RAW MATERIALS FOR PORTLAND CEMENT.

Sources of Lime.

Lime may be obtained from limestone, marble, chalk, marl, alkali waste, or furnace slag. Limestone, when pure, would contain 100 per cent. of carbonate of lime, equivalent to 56 per cent. of lime oxide (CaO) and 44 per cent. of carbonic dioxide (CO_2); but limestones in nature do not reach this theoretical composition, and therefore contain various impurities as magnesia, silica, alumina, iron, etc.

Most limestones have been formed from the accumulation of the calcareous shells and skeletons of crinoids, corals, and molluscan shells on the ocean floor. As these lime structures accumulated and disintegrated into lime mud by the mechanical action of the waves and by chemical solution, various foreign ingredients would become intermingled adding clay, sand, and other impurities. By later consolidation and cementation the lime sediment would form limestone.

Some limestones have been formed as chemical precipitates. River and ocean waters contain lime carbonate in solution, and on evaporating would deposit lime forming calcareous rock. This formation of limestone does not usually take place on a very large scale, and it is generally conceded that the large deposits of limestone have been formed through organic agencies.

Since the water in which limestones were formed also contained magnesium carbonate the process of replacement of lime carbonate by magnesium carbonate has taken place to a greater or

less extent, so that nearly all limestones contain a percentage of magnesium carbonate. Where the amount of magnesia is small, the rock is called limestone, but when the percentage reaches 15 or 20 per cent. or more, it is often called a dolomite. The typical dolomite contains 35 to 40 per cent. of magnesium carbonate and 60 to 54 per cent. of lime carbonate. In selecting a limestone for Portland cement manufacture there should be a low magnesia percentage.

Limestones have a wide geological and geographical range, being found in all the geological horizons and in nearly all countries and states. They are not always adapted to cement manufacture, being in some cases too high in impurities, and in other places lacking uniformity in composition.

If the percentage of injurious impurities is within safe limits and the other impurities are fairly constant, giving a limestone of uniform composition, it is possible in many cases to use it with other materials forming a proper mixture.

A limestone high enough in alumina and too low in silica can be used according to Orton¹ by adding finely ground sandstone. In the example quoted the resulting cement was slow setting and had 20 per cent. higher tensile strength than the best commercial cements.

Marble represents a limestone altered or metamorphosed by heat and pressure and so rendered crystalline. The rock could be used for cement though it would be more expensive on account of greater difficulty in grinding.

Some limestones have nearly the correct proportion of impurities for an ideal Portland cement rock. The Lehigh Valley cement rock in Pennsylvania is an argillaceous (clayey) limestone, containing almost the required amount of silica and alumina, but is too low in lime. A small amount of pure limestone is added to correct the natural mixture, making a high quality of cement with but little trouble in regulating the mixtures. The cement rock and limestone found near at hand have the following composition:²

1. Ohio Geol. Survey, Bull. 3, p. 224.

2. Mineral Industry, Vol. VI., p. 97.



Plate XXXIII.—View of the Buckhorn Portland Cement Mill and Gravity Incline.

to 40 feet near the center of the deposit. An average of 84 samples shows the following composition:¹

Silica	2.08	per cent.
Iron and aluminum oxides.....	2.59	" "
Lime carbonate.....	88.06	" "
Magnesium carbonate.....	0.32	" "
Sulphuric anhydride.....	0.78	" "
Organic matter.....	5.30	" "
	99.13	

Exclusive of organic matter the average would be 93.10 per cent. of carbonate of lime.

Alkali Waste. In the manufacture of caustic soda there is a large amount of waste carbonate of lime produced, which if low enough in sulphur and magnesia may be used as a source of lime for Portland cement.

The Michigan Alkali Company in their Wyandotte plant use a mixture of 100 parts of clay to 260 parts of waste burning to a dark green clinker, using the wet process of mixing.²

Slag, as a waste product of blast furnaces smelting iron ores, consists mainly of lime, silica and alumina, with small amounts of magnesia, iron and sulphur. If magnesia or sulphur runs high the slag cannot be safely used. The slag is mixed with limestone and the mixture ground and burned.

The composition of the alkali waste and the furnace slag used for cement manufacture is shown by the following analyses:³

	Alkali waste.	Slag.
Silica	1.98	35.0
Alumina	1.41	14.0
Iron oxide.....	1.38	1.2
Lime oxide.....	48.29	49.0
Magnesium oxide.....	1.51	3.5
Alkalies	0.64	....
Water and organic matter.....	3.80	....

Slag cement, which is made at a number of places in this country, is a different material from Portland cement. For this cement, the slag is rapidly cooled by passing it while hot into cold water, thus granulating the slag. Slaked lime is then added and the mixture ground to a fine powder without burning, forming a hydraulic cement.

1. Mich. Geol. Survey, Vol. VIII., part III., p. 344.

2. Geol. Survey of Mich., Vol. VIII., pt. III., p. 248.

3. Geol. Survey of Alabama, Bull. 4, pp. 31, 32.

If the slag is cooled slowly the hydraulic properties are not developed. According to Tetmayer,¹ "The hydraulic activity of a slag depends in the first place on its basic character expressed sufficiently by the ratio of lime to silica. The most favorable ratio of lime to silica and to alumina is approximately 46% CaO: 30% SiO₂: 16% Al₂O₃=1.00: 0.65: 0.35 or Ca O (lime): SiO₂ (silica)+Al₂O₃ (alumina)=1.00 to 1.00."

Sources of Silica and Alumina.

The rock used for the lime in Portland cement is usually too low in silica and alumina, so that other materials must be added to furnish the correct proportion of these elements.

If only silica is needed, finely ground sandstone of high degree of purity may be added. If, as in the cement rock of Lehigh valley, the proportion of silica and alumina is sufficient, and lime is too low, a pure limestone may be added. If the lime percentage is sufficient and alumina and silica are too low, then clays or shales may be added in certain determined proportions.

The origin and different physical and chemical properties of clays and shales have been discussed in detail in Part I. of this report. Not all clays and shales are adapted to cement manufacture, so that it becomes very important to select the proper grades. The following factors are given by Bleininger² as determining the character of the clay or shale to be used in cement mixtures:

1. The clay must have a percentage ratio of silica to alumina of from 3:1 to 4:1. If the clay is high in alumina it sets too fast and does not attain sufficient strength. If too high in silica, its fusion point is raised requiring more heat and greater wear on the rotary kilns. The sum of silica and alumina in the hydrous clay should not exceed 87 per cent.

The Martinsburg shales have:

Silica	56.67 per cent.	56.29	53.30
Alumina	19.52 " "	17.85	18.16
Or ratio silica to alumina.....	2.90:1	3.15:1	2.93:1

The silica content might be increased by adding crushed sand, but in all probability the average shale would be high enough in silica to give the correct ratio.

1. Quoted in Ohio Geol. Survey, Bull. 3, p. 43.

2. Ohio Geol. Survey, Bull. 3, p. 223.

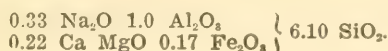
This ratio can also be expressed in molecular proportions, which would give the limits as 5 molecules of silica to 1 of alumina and 6.66 molecules of silica to 1 of alumina.

To determine this molecular ratio, the formula is calculated from the clay analysis, taking alumina as unity. The percentages of the different constituents are divided by their respective molecular weights and each quotient divided by the alumina quotient.

For example, the clay near Hendricks contains:

	Per cent.		Molec. wgt.	Alumina
Silica (SiO_2).....	67.10	÷	60	$=1.118 \div .183 = 6.10$
Alumina (Al_2O_3).....	18.74	÷	102	$=0.183 \div .183 = 1.00$
Iron oxide (Fe_2O_3).....	5.14	÷	160	$=0.032 \div .183 = 0.17$
Lime (Ca O).....	0.96	÷	56	$=0.017 \div .183 = 0.09$
Magnesia (Mg O).....	0.96	÷	40	$=0.024 \div .183 = 0.13$
Sodium (Na_2O).....	2.40	÷	39	$=0.061 \div .183 = 0.33$
Water.....	4.69			

Giving a formula



This clay has a molecular ratio of silica to alumina of 6.10 to 1. Its percentage ratio is 3.5 silica to 1 of alumina, so as far as the relation of silica and alumina is concerned it would be adapted to use in Portland cement.

2. The clay or shale must not contain so much magnesia that the magnesia content of the cement rises above 3 per cent. or possibly 5 per cent.

3. The clay or shale should contain at least 3 per cent. of ferric oxide, but not sufficient to raise the ferric oxide content of the cement over 4 per cent.

4. The clays or shale should be low in sulphur and should not contain more than 1 per cent. of sulphur in any form.

5. The material should be free from any irregularly distributed matter as concretionary iron carbonate, or lumps of lime carbonate.

PROSPECTING FOR CEMENT MATERIALS AND LOCATION OF MILLS.

As has been shown in the preceding pages the chemical composition of the materials to be used in the manufacture of Portland cement must be carefully determined in order to know whether the chemical constituents can be brought to the proper

proportion by mixtures, or whether the percentage of injurious elements is too high so that the materials would have to be rejected.

The analyses should be made by a good chemist. When the proportions of ingredients are found by such analyses the adaptability for cement manufacture may be determined by the tests outlined in this chapter.

The hardness of the limestone, clay or shale will have a bearing on the cost of manufacture as involved in power required, wear and tear on grinding machinery.

In selecting samples for examination, it is a waste of time on the part of the prospector and the chemist to take a sample of material from a single place. It is not unusual for a piece of rock, a few inches in diameter, to be sent in to the survey office with a request for examination as a cement rock, and a report on such a specimen is of little value.

The area and thickness of the rocks should be measured and samples taken from the various parts of the deposit. These samples should represent average conditions. A vertical section of the rock to be used may be selected and samples taken from top to bottom, these should be thoroughly mixed and divided, thus giving an average of the stone at that particular location. If the layers of rock show variations each stratum should be examined to determine what may be used and what must be rejected, a condition which involves increased expense in the use of the materials and may prevent the use of the rock. The sampling should be repeated at intervals throughout the area of the formation to be used.

The surface rock will probably differ from that at the middle or bottom. The rock may be valuable for cement in one place and vary in another so as to require very different treatment or even be worthless. Extra precaution in sampling may avoid expensive mistakes later in the development.

A stratum of limestone a few feet thick even of the highest grade would not be sufficient for the establishment of a cement mill. The thickness and extent may be determined where ravines cut across the rocks or along steep hillsides where the rocks are exposed. Where the rocks are not exposed to sufficient depth borings should be made. In the case of clays or even shales this is not difficult, pits may be sunk or auger borings made. In lime-

stone diamond drill cores should be obtained, quarry openings will aid, but not for the whole area, unless these are numerous which is rarely the case.

If the rock has a heavy cover of soil or other rock materials the expense of stripping may be too great for profitable work. The amount and character of this cover should be taken into consideration.

The relation of the lime material and the silica-alumina material is important. The ideal location would be where both materials occur together and such associations are found. If the two materials are remote from each other, the cost of transportation of the crude rock will be a detriment and may prevent the profitable location of a mill.

Fuel represents a very important item in the cost of the manufacture of cement. Location of good cement materials in sections where fuel is very expensive may ruin the district for cement manufacture. Cement mills have been successfully operated where the fuel is shipped long distances, but in such cases there must be compensating advantages, as location in or near large cities where the freight rate is reduced to a minimum. The St. Louis Portland Cement Company secures their coal supply from West Virginia, and on account of the low cost of transportation to a large city market is able to successfully compete with other companies located close to a fuel supply but with a higher freight rate over the longer distance to this market.

Some experts estimate the cost of fuel at 60 per cent. of the total cost of manufacture, but this would be under very exceptional conditions. Other estimates place the cost at 30 per cent.

From the experience in one mill, it requires about 200 pounds of coal to burn a barrel of cement and furnish the necessary power. Coal costing \$2.00 a ton would bring the cost of fuel per barrel of cement to 20 cents. In using natural gas it would require about 2000 cubic feet. Gas in many parts of West Virginia can be used at a cost of 5 cents a 1000 for manufacturing purposes, which would bring the fuel cost per barrel of cement to 10 cents, including that used for drying, burning, power for grinding and motive power.

The mere fact of the cement deposits being located near large coal mines does not insure cheap fuel for this work, since

all coals are not adapted to cement burning. The coal to be used must have high heating power, low sulphur, and a high percentage of volatile matter. As will be shown in the next chapter the coal is pulverized and fed into the kilns as coal dust under air blast. It must therefore generate sufficient heat, give a maximum temperature about 12 feet from the point of entrance, and preserve a high temperature well through the length of the kiln, leaving it at the stack with as little waste heat as possible.

As the fuel is thus burned in the kiln, and the ash becomes mixed with the cement, the percentage of ash should be low and free from sulphur. The cost and character of the fuel become important matters to be determined. The standard coal used in the cement mills as far west as St. Louis and north into Michigan is the Pittsburg seam from the mines of the Fairmont region in the Monongahela valley. This State thus possesses great advantages in fuel for cement locations, with the natural gas and coals of the Pittsburg seam and also a number of coals in the Kanawha valley. The chemical composition of the West Virginia coals is given in volume II. of the reports of this survey.

The following analyses taken from volume II. show the composition of the Pittsburg coal used in many of the cement mills of this country and two of the Kanawha river coals.

	Pittsburg. ¹	Kanawha.	Kanawha.
Fixed carbon.....	53.83	59.82	57.97
Volatile matter.....	37.47	34.70	37.66
Moisture	1.43	0.76	0.61
Ash	7.27	4.72	3.76
Sulphur	2.59	1.18	1.28

These analyses will afford a good guide for the best coals for cement burning. Natural gas, when available, makes an efficient and cheap fuel, lowering the cost of fuel and labor.

The cost of labor is another matter of importance, as in the days of active competition the cost of production must be kept to the lowest point. According to Bernard Green the cost of labor in cement manufacture represents 87 per cent. of the total, divided as follows:²

1. Average from fifty-one mines.

2. Jour. Assoc. of Eng. Societies, Vol. XX. No. 6, 1898.

Labor in quarrying.....	40	per cent.
Labor in burning.....	6	" "
Labor in grinding.....	6	" "
Labor in moving, etc.....	5	" "
Labor in packing.....	3	" "
Labor in coal, staves, heading.....	27	" "
Total.....	87	" "

This estimate is too high for average conditions. Other estimates give 35 per cent. for cost of fuel, 45 per cent. for labor, and 20 per cent. for incidental expenses.

In the Ohio Geological Survey report¹ an estimate is given on cost of manufacture per barrel as follows:

LABOR.

Quarry	\$0.050
Crushing and drying.....	0.005
Grinding	0.015
Burning	0.015
Power generation.....	0.011
Coal grinding.....	0.010
Yard work.....	0.015
Machine shop.....	0.0225
Miscellaneous	0.0025

\$0.15

RAW MATERIALS.

Coal	0.225
Gypsum	0.0125

ACCESSORY EXPENSES.

Repairs	0.04
Oil	0.02
Miscellaneous	0.03

0.09

Packing and loading.....	0.04
Works and management.....	0.02

0.06

Interest on investment (\$700,000).....	0.07
Sinking fund and deterioration.....	0.10
Management and selling expenses.....	0.065

0.235

Total per barrel.....\$0.7725

In Michigan² the cost of manufacture per barrel of cement is estimated at

1. Bull. 3, p. 330.

2. Geol. Survey of Michigan, Vol. VIII., pp. 167, 178, 184, 185.



Plate XXXIV—View of the Buckhorn Portland Cement Quarry.

Mining and hauling to mill.....	\$0.100	(8 to 17 cents).
Burning	0.172	
Clinker grinding.....	0.088	
Power	0.093	
Packing	0.0255	
Total.....	<u>\$0.4785</u>	

To this estimate should be added the interest, deterioration, management and selling expenses as listed above, \$0.235, making total cost of \$0.714 per barrel. The average cost is given in Michigan report at 68 cents per barrel. These estimates are based on a production of 1,200 barrels a day. Plants of larger capacity will reduce cost of manufacture per barrel. Electrical power and rope transmission will lower cost of power. There will be also, as has been shown, a variation in cost of fuel in different localities.

The matter of location of the deposits should be carefully considered. The plants should be near a railroad giving good connections with the market with as short haul as possible. If the mill can be located with convenient rail and water transportation this will be an added advantage. A barrel of cement weighs nearly 400 pounds, and with a 10 cent freight rate this means an additional cost of 40 cents a barrel, which may shut the cement out of a market reached by other mills by a shorter route.

If the mill is located at a distance from the crude materials there is an additional cost of transportation of these materials. If the mill is located near deposits remote from town, there is apt to be trouble in securing labor.

Finally, it must be remembered that a Portland cement mill of good capacity is an expensive plant to build, requiring a large amount of capital, and it may be some time before good deposits of cement materials in favorable locations attract capital; but with the increasing demand for cement, the favorable locations will gradually be developed.

A State like West Virginia with good deposits of raw materials, excellent railroads and water transportation to large markets, cheap and abundant fuel, should be a prominent cement producing state, a condition which will doubtless be realized when the deposits of raw materials are exploited and advertised.

CHAPTER XVIII.

PROCESS OF MANUFACTURE OF PORTLAND CEMENT.

1. Mining of the materials.
2. Crushing.
3. Drying.
4. Mixing.
5. Grinding of the raw materials.
6. Burning.
7. Cooling the clinker.
8. Reduction of the clinker.

1. *MINING OF THE MATERIALS.*

The clay or shale is obtained on a small scale by pick and shovel, or by wheel scrapers, or on a larger scale by steam shovels. If the material is hard and compact, it is blasted out, the rock broken down and worked in benches. Limestone is usually worked in open quarries, the rock being blasted and broken into masses convenient to handle by sledges. Marls are worked in open pits similar to clay deposits, or where they are covered with water, by clam shell or bucket dredges.

The materials are hauled to the mill in dump carts, or in mine cars by horse, cable, or small locomotive. In some plants aerial cable trams are used for this purpose. If the distance from the plant is several miles, the material must be transported by rail. In Michigan, where marl was transported 30 miles, the estimated cost of mining and haulage was over twice that of deposits located near the mill.

2. *CRUSHING OF THE RAW MATERIALS.*

Soft materials like clay, chalk, and marl are readily broken up in the grinding of the mixtures and usually require no preliminary crushing. Where they are crushed, rolls or disintegrators are used as in ordinary clay working plants. Limestone and shale, as they are brought from the quarry, are ground in one of several types of crushers.

The Jaw type of crusher is represented by the Champion and Blake patterns, (shown in figures 6 and 7) in which there is a ver-

tical stationary jaw and a swinging apron jaw operated by an elliptical cam giving it a forward and backward motion. The jaws form a V shaped box, with the size of crushed fragments determined by width of opening below, which is adjustable. The faces of the jaws are made of chilled iron or hardened steel.

The gyratory crusher is represented by the Gates and Austin types and is especially popular for cement work. These types have a conical spindle rotating within a conical shell on an eccentric which gives in addition to the rotary motion a backward and forward movement of the spindle head. There is a continual crushing force executed on the fragments as they fall downward to the outlet. This crusher is illustrated in plate XXVI.

The crushers of sizes Nos. 5, 6, 8 are used especially in cement mills. The variations given in the table for capacity and horse power required depend on the character of the rock to be broken. The lower figure for capacity refers to very hard ballast rock like granite. Ordinary limestone would come nearer the larger figures.

The shale is usually broken in a disintegrator of the Williams type, illustrated in figure 11. This machine has a series of hammers attached to discs on a central shaft, hung so as to fly outward from the center of the shaft which revolves at high speed. Such a machine, according to its size, and character of the material, will crush 25 to 400 tons of shale a day.

3. *DRYING THE RAW MATERIALS.*

After the limestone is crushed to a gravel and the shale is finely ground, they are dried in rotary dryers. The Allis-Chalmers, or Ruggles-Coles dryers, as used in many cement mills, consist of a brick lined iron shell 54 inches in diameter and 40 feet long, revolving on two sets of rollers driven by a chain of gearing.

The heat is produced in a brick furnace at one end with coal fuel, the furnace gases and moisture pass out through a stack at the opposite end. The material is charged at the stack end and leaves heated at the furnace end, where it is taken by conveyors or elevators to the mixing bins.

The Ruggles-Coles dryer, shown in plate XXVII., consists of two shells made of heavy steel plates. The inner cylinder is connected by hot air flue with the furnace. The dryer turns on two steel tires, each resting on four bearing wheels. Between

DETAILS OF GATES CRUSHER.

Size.	Receiving Opening.	Weight Pounds.	Capacity per Hour in Tons to Pass Through Ring of			Size of Product. Inches.	Size of driving pulley. Inches.	Rev. of Pulley per Minute.	H. P. Required.
			2½" dia.	3" dia.	5" dia.				
5	10x38	31,200	35 to 60	45 to 75		1¾	36x14	375	22 to 30
6	12x44	45,500	50 to 60	60 to 100		2	40x16	350	28 to 45
7½	14x52	64,800	65 to 100	75 to 120	130 to 200	2½	44x18	350	50 to 75
8	18x68	100,000		100 to 145	165 to 240	3	48x20	350	70 to 110
9	21x76	153,000			240 to 320	4	56x20	300	100 to 150

DETAILS OF AUSTIN CRUSHER.

Size.	Receiving Opening.	Weight Pounds.	Capacity per Hour in Tons to pass 2½" ring.	Size Driving Pulley. Inches.	Revolutions of Pulley per Minute.	H. P. Required for crusher, ele vator, screen.
5	8x27	23,500	15 to 30	32x12	400	25 to 30
6	12x35	32,000	25 to 50	36x14	375	30 to 50
7	12x36	44,000	30 to 60	40x16	350	40 to 60
7½	14x45	67,500	75 to 125 (3 inches)	44x18	350	75 to 125
8	18x63	100,000	125 to 200 (3½ inches)	48x20	350	100 to 150

the tires is a heavy cast gear driven by a pinion, shaft and pulley.

In operation the heated air passes through the inner cylinder and returns between the outer and inner cylinders and the material to be dried is taken up on the projections on the cylinders and dropped through the current of heated air, until by the inclination of the machinery the dried material is discharged at the opposite end.

A test of the Ruggles-Coles drier at the Alsen Portland cement plant gave the following results:

Material tested: <i>Plastic Clay.</i>	
Duration of test.....	2 hours.
Moisture in material.....	23½ per cent.
Amount of clay fed to drier per hour.....	18,937 pounds.
Amount of clay delivered by drier per hour.....	14,486 "
Amount of water evaporated.....	4,166 "
Amount of coal burned per hour.....	550 "
Water evaporated per pound of coal.....	7.57 "

4. MIXING OF THE RAW MATERIALS.

One of the most important steps in the Portland cement manufacture is the intimate mixture of the raw materials. Any lack of uniformity in the mixture will cause serious defects in the cement.

There are three methods in use for mixing the ingredients for cement.

1. The dry method where clays or shales, and limestones or chalk are used, or where two grades of limestone are used, as in the Lehigh valley.

2. The semi-dry method used for clays or shales and limestone in a number of western plants.

3. The wet method, where marl is used with clay or shale.

The proportions of the materials to be used are weighed on ordinary scales, or by automatic weighing machines. These materials are mixed to some extent in weighing and in the screw conveyors carrying them to the grinding department, but the intimate mixture is brought about by fine grinding in the dry method, by fine grinding and agitation in water in the semi-dry and wet methods.

5. GRINDING OF THE RAW MATERIALS.

After the materials are ground to size of gravel, dried and the proper proportions weighed out, the mixture is ground to a fine flour in mills adapted to such work.

The following mills are in use :

Millstones.
Griffin mill.
Kent mill.
Ball mill.
Kominuter.
Tube mill.

Millstones.—In the foreign cement mills, and in a number of Michigan plants, French buhr-stone mills are used for fine grinding. In all these plants soft materials, as chalk, marl and clay, are used. The method gives small capacity and requires skilled stone dressers to keep the mills in good condition, thus making the work expensive.

Griffin Mill.¹—The Griffin mill is used in a large number of American cement mills, both for fine grinding of the raw materials and of the clinker. The machine was patented (No. 409,579) August 1889. In 1892, 420,000 barrels of cement were ground in the United States, and in 1902, 9,120,000 barrels were ground with these mills.

This mill will pulverize from 30 to 250 mesh, with a capacity of $1\frac{1}{2}$ to $2\frac{1}{2}$ tons per hour. As shown in plate XXVIII, the power is received by a horizontal pulley (17) from which is suspended the shaft (1) by means of a universal joint (9), and to the lower extremity of this shaft is rigidly attached the crushing roll (31) which is free to swing in any direction in the case.

The case consists of the base or pan (24) containing the ring or die (70) against which the roll (31) works and upon the inner vertical surface of which the pulverizing is done.

In dry pulverizing this pan or base (24) has a number of openings through it downward, outside of the ring or die, which lead into a pit from which it is delivered by a conveyor. Upon this base is secured the screen frame (44) which is surrounded with a sheet iron cover (45) and to the top of which is fastened a conical shield (25) open at the apex through which the shaft works.

Within the pulley (17) is the universal joint (9) composed of the ball with trunnions attached which work in half boxes (11) and slide up and down recesses in the pulley-head casting (16). A cover (13) keeps the working parts away from all dust and grit.

The roll is revolved within the die in the same direction the shaft is driven, but when coming in contact with the die it travels around the die in the opposite direction from that in which the roll is revolving with the shaft, thus giving the mill two direct actions on the material to be ground. There is a pressure by cen-

1. Description furnished by Bradley Pulverizer Co., Boston.

trifugal force of 6,000 pounds brought to bear on the material being pulverized between the roll and the die, the united actions being very effective in their combination.

When a quantity of material to be reduced has been fed into the mill sufficient to fill the pan as high as the shoes or plows on the lower side of the roll, they work in it, stir it up, and throw it against the ring, so that it is acted upon by the roll; and when in operation the whole body of loose material whirls around rapidly within the pan, and being brought between the roll and die,

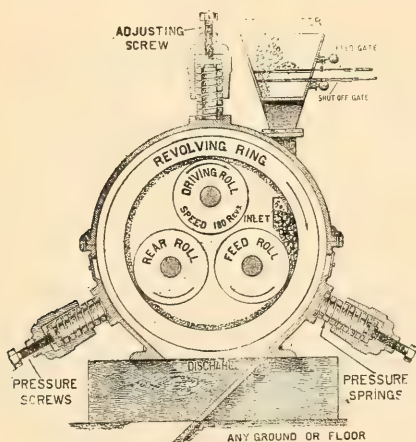


Fig. 37.—Kent Mill—Sectional Plan.

is crushed and all that is sufficiently fine passes at once through the screen above the die, the coarser portion falling down to be acted upon again.

The pan (7) attached to the shaft above the roll draws air in at the top of the cone, forcing it through the screens and out into the discharge, thus effectually keeping all dust within the mill.

In working dry the screen which surrounds the pulverizing chamber is of much coarser mesh than the delivered product; for example, a 16 mesh screen delivers a product over 90 per cent. of which will pass a 60 mesh screen.

Two sizes of the mill are made, designated as 30 and 36-inch mills, so called from the inner diameter of the ring or die against which the roll runs. The 30-inch mill weighs 10,500 pounds, requires 15 to 25 H. P. The roll is 18 to 20 inches in diameter, the

weight 100 pounds, weight of ring 260 pounds, pressure of roll against die 6,000 pounds. The 36-inch mill weighs 14,500 pounds, with weight of roll 175 pounds, die 408 pounds, and a pressure of roll against the die of 8,000 pounds.

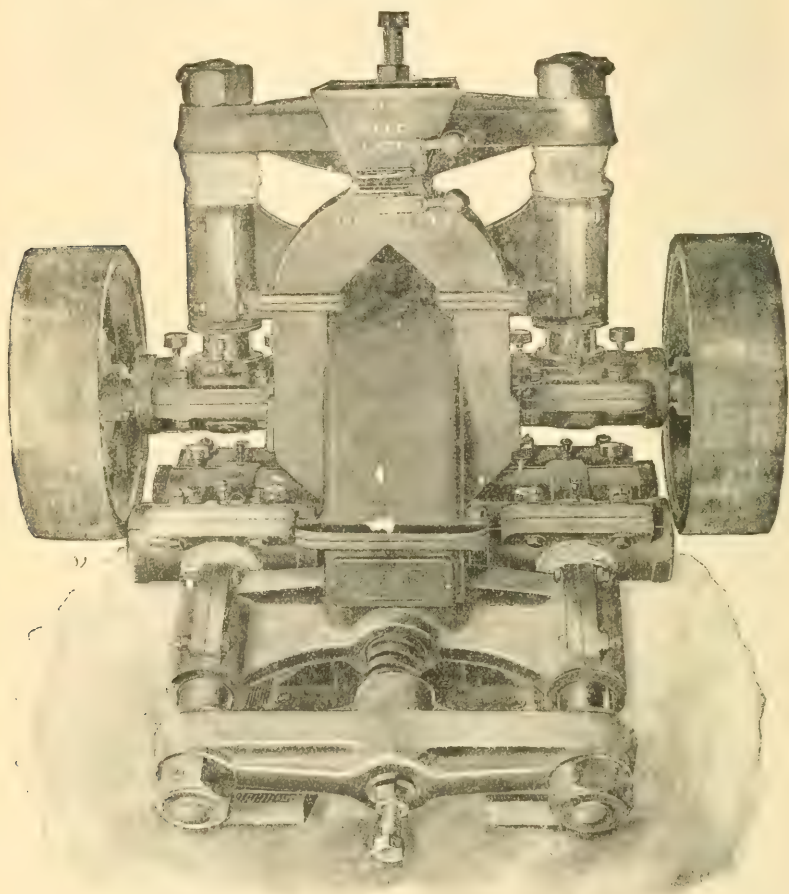


Fig. 38.—The Kent Mill.

Kent Mill.—This mill consists of a revolving ring and three rollers pressing against its inner face as shown in sectional drawing in figure 37. Springs support the rolls, and these support the ring so that the four crushing parts are free to move. The material added through the hopper falls on the inner face of the ring where it is held by centrifugal force.

The rolls are pressed by the springs against the rock on the ring with a pressure adjustable to 20,000 pounds. The crushed rock passes from each side of the ring into the casing and through an outlet pipe. 90 per cent. of the rock is claimed to be abraded on itself in crushing so that wear on the parts of the machine is slight. The Kent mill is illustrated in figure 38. The speed is 180 revolutions per minute, and capacity with limestone about eight tons per hour, requiring 25 H. P.

The Raymond impact pulverizer is a roller mill with the rollers revolving around a central upright shaft, and an air separator attached which draws the material from the rolls as it is ground and separates it into fine powder, returning the coarse tailings to the mill for further grinding. It is claimed by the company to do the work of a ball and tube mill combined with one-half the horse power.

Ball Mill.—The ball mill was originally designed and used for reducing materials from lump state to the proper fineness in one operation. This method required the use of outside fine screens which for cement work where extreme fineness is required, gave small capacity and caused much difficulty in keeping the fine screens open. Yet with these disadvantages it proved more economical than the use of millstones.

After the invention of the tube mill, the ball mill was used for preliminary crushing only, its product passing through a 30 mesh screen goes to the tube mill for fine grinding.

Steel balls, two to five inches in diameter, are placed in the mill, and by their movement grind and crush the material. The capacity of the mill is estimated at 100 per cent. per ton of balls.

The ball mill consists of two circular side plates provided with inwardly projecting and eccentrically located shelves. The side plates have attached to them rigidly at their centers hubs, which are mounted on a heavy shaft. The Gates ball mill is shown in figures 39 and 41.

Resting upon the inwardly projecting shelves and reaching from one side plate to the other are the wearing plates which are eccentrically arranged so that one plate passes behind the next one, thus producing a step and also providing an opening through which residues from the screens are returned to the mill. The tumbling of the balls and material due to revolving the drum rapidly reduces the material to a fine grit and powder, the steps

carrying the balls upward so as to fall from an elevation on the material, increases the grinding effect.

When partially reduced, the ground product falls through apertures in the wearing plates to the first screen. The tailings from the screen are promptly returned to the mill through the

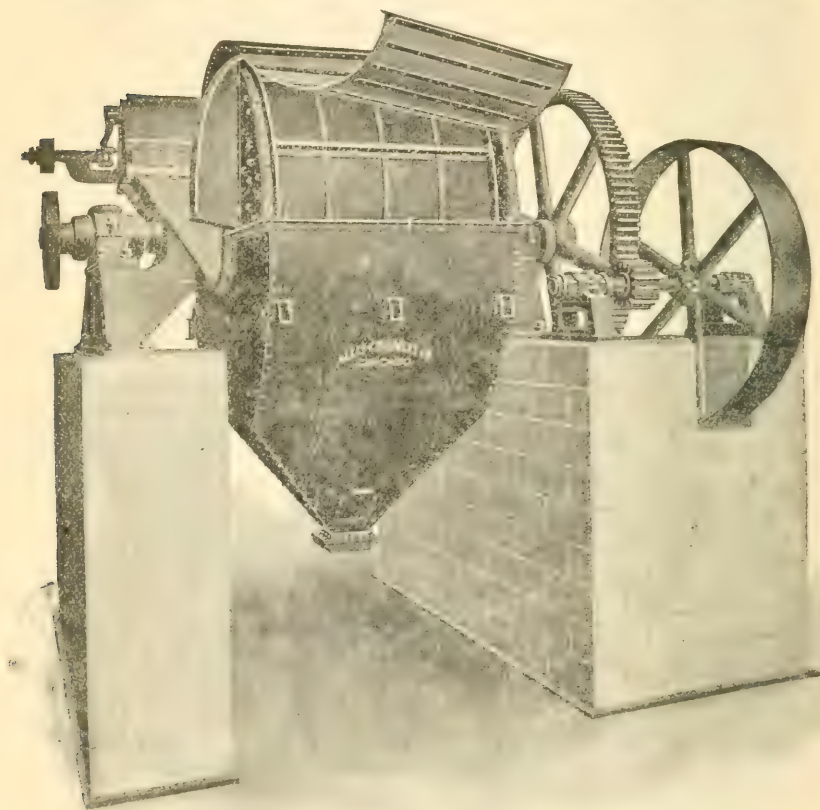


Fig. 39.—Gates Ball Mill with Feeder.

openings between the overlapping plates. The screened material falls upon the second screen and the tailings from it are returned to the mill while the fine material goes to the outside finishing screen and the part going through falls into the dust proof hous-

ing and is removed by conveyor for final grinding. The residues in all cases are returned to the mill for further grinding.

The highest efficiency in the ball mill is to be obtained by constant and regular feeding. It is almost impossible for a workman to control the inflow of material in any regular manner. This is usually accomplished by an automatic machine feeder, consisting of a revolving plate on which the material falls and a scraper which throws a sufficient stream of material into the mill, in the Smidth pattern, and by a swinging ball feeder made adjustable in the Gates mill.

DETAILS OF GATES BALL MILL.

Size.	Weight with- out balls.	Weight of charge of balls.	Capacity on Portland cement clinker to 20 mesh.	H. P. required.
7	29,500 lbs.	3000 lbs.	12 to 16 bbls. per hr.	30 to 40
8	41,100 lbs.	4500 lbs.	18 to 24 bbls. per hr.	40 to 50

From 100 to 120 per cent. additional power is required momentarily in starting these machines. When pulverizing to pass through 20 mesh screen, from 30 to 40 per cent. will pass a 100 mesh sieve.

Kominuter.—This machine as made by Smidth & Company is a modified ball mill made in a cylindrical barrel form and so arranged that the material from the inlet end travels to the opposite end across a solid instead of a perforated plate, and the screen is thus protected from the action of the balls. The material then travels back to the inlet end over a conical screen. A larger charge of balls can be used, reaching 6,600 pounds, the discharge openings are not subjected to impact of the balls, and the machine is claimed to give a much larger capacity with same power and size than the regular ball mill. The Smidth kominuter is shown in figure 40.

Tube Mill.—The tube or pebble mill consists of a wrought iron tube mounted as a shaft by the attachment of dome shaped ends which rest in bearings. The tube is lined with chilled iron, or stone silex, and is about half filled with hard flint pebbles. The shaft at the feed end is hollow and a screw conveyor carries in the material, and it is delivered ground at the opposite end.

The Bonnot tube mill is illustrated in figure 41-a, and the Smidth tube mill in plate XXXI.

The pebbles are imported from northern Europe where there are abundant deposits of very hard pebbles. Four sizes, 2 to $1\frac{1}{4}$ inches in diameter, are charged into the mill, and as they wear

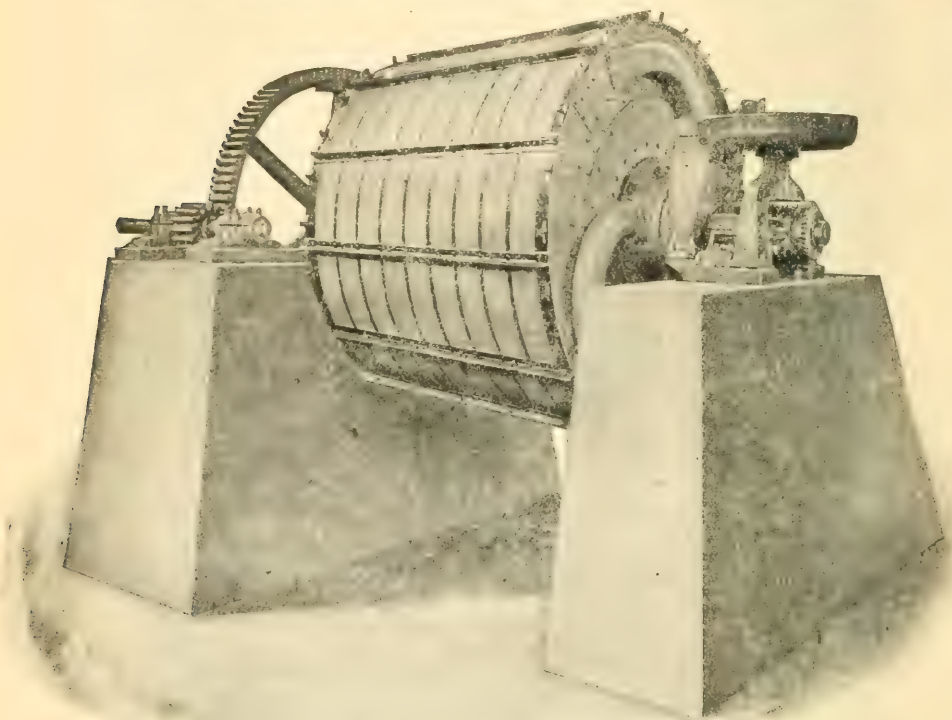


Fig. 40.—Smidth Kominuter for Grinding Cement.

down are replaced with the larger size. When used in grinding of clinker they wear on an average of one pound to 30 barrels of cement. The pebbles cost about \$25 per 1000 kilograms (2204) pounds.

The common size of tube mill is 22 feet long and 5 feet in diameter. This size will grind about 6 tons of raw material per hour, or of clinker about 14 to 20 barrels an hour, requiring 70 to 80 horse power. The mill is run at low speed. The velocity at

which the tube revolves tends to carry the mixture of pebbles and material to a certain height in the mill from which point pebbles and material fall together with rolling and grinding as they fall to the bottom of the mill.

The exact grinding action in a tube mill has been recently studied in detail by use of experimental glass mills by Fischer. The following facts were observed on an experimental mill three feet in diameter as quoted in the Ohio Survey volume on cement.¹

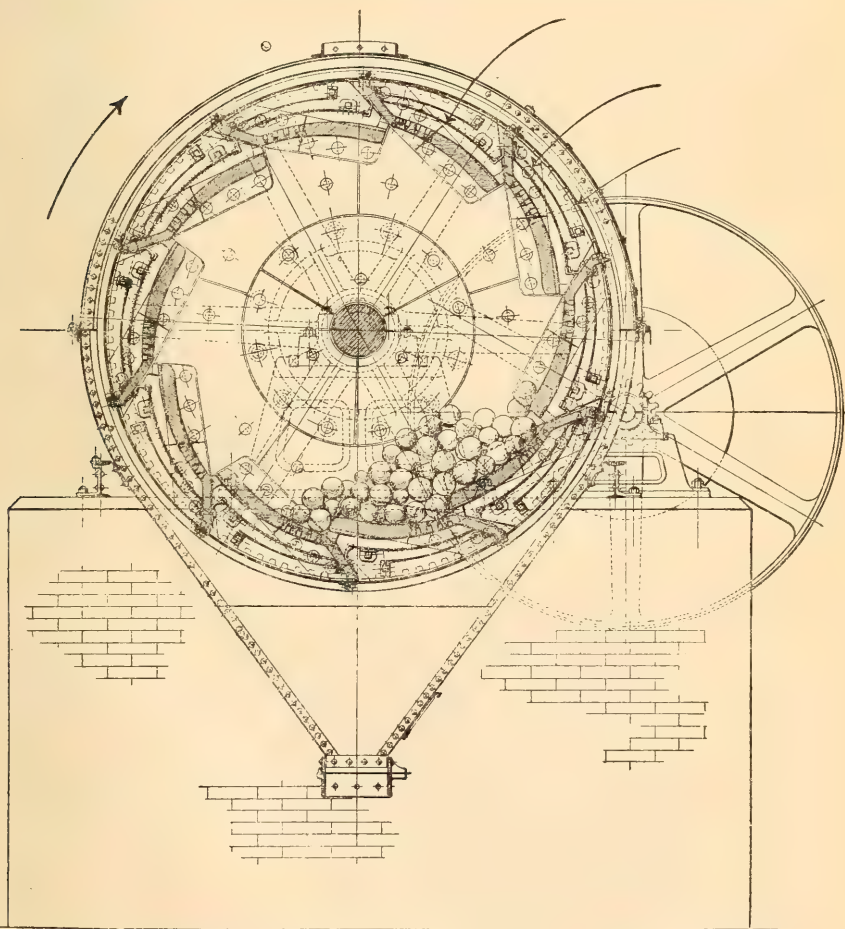


Fig. 41.—Gates Ball Mill—Sectional View.

1. Zeitschrift des Vereins Deutscher Ingenieure No. 13, 1904. Quoted in Ohio Geol. Survey, Bull. 3, p. 274.

"When at rest the pebbles showed a height of 450 mm. The mill was now rotated with a speed of $23\frac{1}{2}$ revolutions per minutes, and it was found that the pebbles rolled down the side rather slowly. On increasing the speed the pebbles seemed to loosen, and they rose to a height of 600 mm. with 32 revolutions. The pebbles have no motion until they are carried up the side of the mill, when at a certain height they become loose and drop back to the bottom, describing a curvilinear path which can be noticed quite distinctly. The pebbles farther away from the surface also do not move with reference to the circumference up to a certain height, but their downward path is more difficult to recognize. On increasing the speed to 35 revolutions the content of the cylinder is loosened still more, so that the pebbles rise to a height of 650 mm.; the downward path becomes quite distinct, and the lower pebbles separate in distinct layers. The pebbles of one layer do not mix with pebbles from the other layers. On speeding up the mill still more, the pebbles at 55 revolutions form a solid ring around the circumference, without any displacement of the balls.

"When material is to be ground it assumes the same motion as the pebbles, distributing itself within the spaces so that it is densest where the latter are loose. No rubbing and rolling between pebbles and the charge takes place anywhere except at the point where the pebbles strike the surface on falling from the highest point. The pebbles climbing up the side of the mill drop away from it as soon as the vertical component of the forces acting upon it is equal to the centrifugal force.

"The grinding effect depends on the vertical distance of the drop, the velocity of the drum, and weight and number of the pebbles."

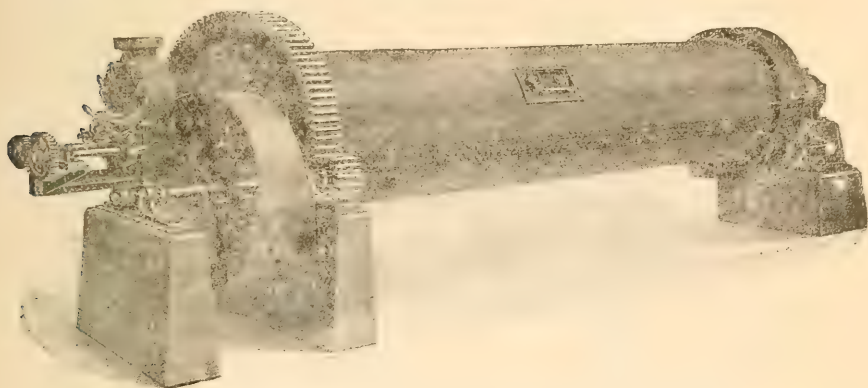
Cause of forward movement of the material in the mill: "As the pebbles descend from their highest point and strike the material to be ground the latter is splashed quite a distance, and if there is much material present, a good deal will thus be distributed, while places where there is little throw off but a small amount. In this manner the material is distributed uniformly. This equalization takes place rapidly, as the velocity of the pebbles is quite great, being often as great as the circumferential velocity of the mill. At the exit the ground material is thrown out through the grating, while the pebbles are retained."

SEMI-DRY AND WET MIXTURES.

In the Iola, Kansas plants the limestone and shale are crushed in Gates crushers, dried in rotary driers, reduced in Griffin mills and mixed with 30 per cent. water in agitator tanks, then burned in rotary kilns.

The agitators are large steel tanks with a central shaft and revolving arms which thoroughly mix the slurry. Analyses are made of the material in the tanks and more limestone or shale added as required. The slurry after thorough mixture is ready for the kilns. This method gives a complete control over the lime and shale mixture and has been very successful in these plants. The semi-dry method is a popular one in a number of English mills.

In the wet method as used in the marl plants of Michigan, the slurry is made with 60 per cent water, and usually there is no preliminary drying of the materials.



6. *BURNING OF THE CEMENT MIXTURE.*

Four types of kilns are used in burning Portland cement :

1. Dome kilns, intermittent, similar to lime kilns.
2. Continuous kilns, of Dietzsch and Schoefer types.
3. Hoffman ring kiln.
4. Rotary kiln.

Dome Kiln.—Dome kilns of the lime kiln pattern are 25 to 35 feet high, tapering to the base, and 10 to 18 feet in diameter, made of stone, brick or iron. They are usually found in the natural cement plants where the fuel and rock are added in alternate layers, the burned product being removed below and new material added at the top.

The early Portland cement kilns¹ were constructed on a similar plan except the operation was intermittent. Wood and coke were piled for several feet above the grate then dried slurry and coke in alternate layers to the doors near the top of the kiln, which were sealed shut after filling the kiln. The fires were started and allowed to burn through the clinker formed to the top, when the kiln was opened, the clinker discharged and the operation repeated. It required 7 to 10 days to fill and burn the kiln, giving a capacity of three to six tons of cement a day. A row of dome kilns is shown in plate XXVII-b.

1. Lewis, Mineral Industry, Vol. VI., p. 106.

The method was expensive in fuel and required considerable labor in sorting the clinker to remove the under and over-burned material. This type of kiln was used for the manufacture of Portland cement in this country until replaced by the rotary kiln in 1889. These dome kilns are still used by some small foreign plants, but they have practically disappeared in Portland cement manufacture. The Johnson kiln as a modified dome kiln is in common use in England. This is an intermittent kiln with long horizontal drying flues between the kiln and chimney. The wet slurry is dried in these flues by the products of combustion of one charge, and the kiln is recharged by taking the dried slurry from the flues and placing it in the kiln with alternate layers of coke.

Dietzsch Kiln.¹—This type of kiln was patented in 1884, and first used in 1886. It is one of the common type of kilns in German cement mills and found in a few American plants. The kiln is continuous in its action. The dried slurry is charged into the chimney near the top and the clinker drawn at the bottom. The upper and lower parts of the stack are separated by the fire bridge, and just below is the combustion chamber, five or six feet deep.

In the chimney above the fire bridge the raw material is heated, and in the shaft below, the clinker is cooled. When the clinker is removed, the mass of slurry briquettes settles to the fire bridge. The slurry is here pulled across the bridge by long handled iron bars thrust through the fire doors, and fills the combustion chamber with the fuel added in sufficient quantity.

The fuel is a powdered coal high in volatile matter so that the flame passes over the fire bridge and up the chimney. The bricks of slurry in the chimney are thus gradually heated and by the time they reach the fire bridge are red hot. They are clinkered in the combustion chamber and cooled by air in the cooling compartment so that the clinker can be readily handled.

The amount of fuel required is smaller than in many other types, but the slurry is dried by artificial heat before it is fed into the kiln, which requires an additional amount of fuel. The labor cost is greater than in the other types, and there is said to be considerable waste in the clinker through under-burning.

Schoefer Kiln.—This type is a modified Dietzsch kiln where the fire bridge is replaced by a narrowed zone above the fire holes.

1. Lewis, Cement Industry, Eng. Record, p. 226.

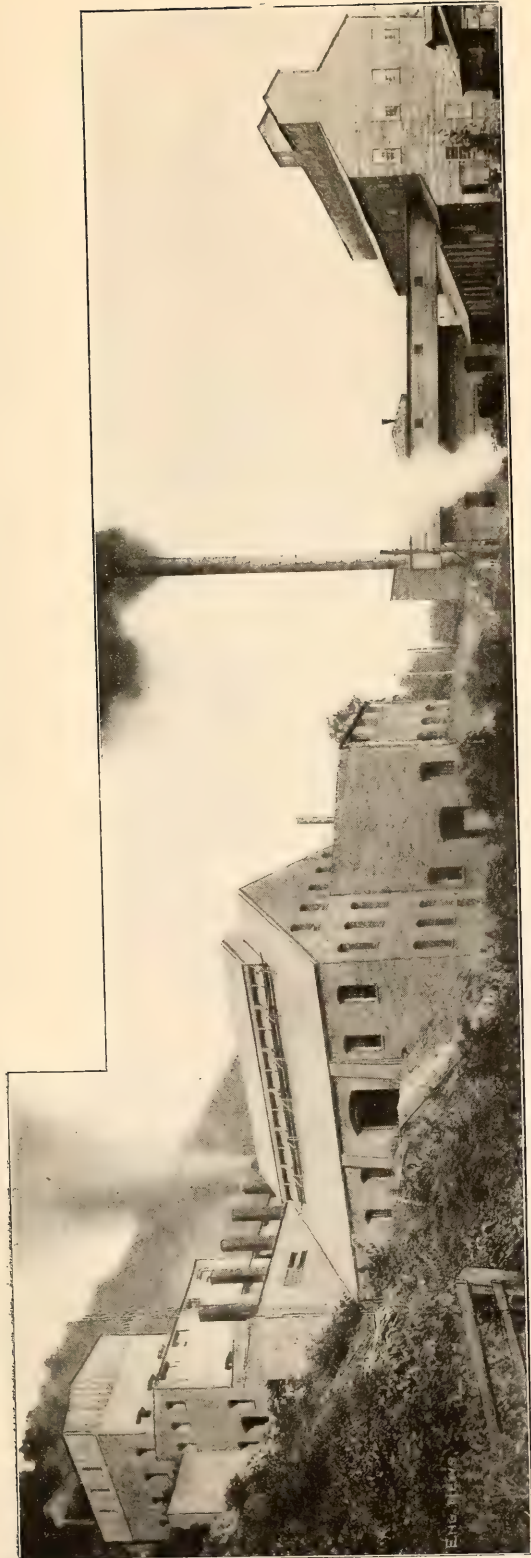


Plate XXXV.—General View of the Buildings of the Buckhorn Portland Cement Co.

Hoffman Ring Kiln.¹—This kiln was originally used in Germany for burning brick. It consists of a continuous gallery of an elliptical shape built around a central chimney. There are usually 15 or 20 compartments with as many entrances from the outside, and as many ports leading into the chimney. In practical working in a kiln of 20 compartments there are, perhaps, six filled with burned clinker, two in process of burning, six filled with bricks of slurry not yet burned.

The connection with the chimney is by the port in the last chamber filled with slurry bricks, and the draft is through the open door of the compartment on the other side which is being discharged of clinker. All other openings to the chimney and to outside are closed. The air is heated by passing through the hot clinker in six chambers and arrives at a high temperature in the combustion chamber. The products of combustion then pass through several chambers filled with bricks to be burned, which are thus heated to a high temperature before burning begins. About one ton of coal is required to produce 6½ tons of clinker. These kilns are used in some of the largest German plants and in a few American mills.

Rotary Kiln.—Probably three-fourths of the American Portland cement is burned in rotary kilns. This type of kiln in its essential features was patented by Siemens in 1869, and adapted to cement manufacture, using producer gas in a patent given to Ransome in England in 1885, and in the United States in 1886.² Its use in England was attended by a series of failures and at the present time it is found in very few foreign mills, but as improved and developed in the United States, it has become the most common form of cement kiln.

The first use of the rotary kiln in this country was by the Atlas Portland Cement Company in 1886 at their plant at Roundout on the Hudson river, and later in the Coplay district, Pennsylvania. From 1892-'96 oil was used as fuel in preference to gas and proved to be cheaper. After that time powdered coal was substituted.³

According to Lathbury and Spackman, the first burning of pulverized limestone and clay in rotary kilns was in 1898, and in

1. Lewis, Cement Industry, Eng. Record, p. 219.

2. Lewis in Cement Industry, Eng. Record, p. 188.

3. Lewis, loc. cit., p. 190.

the same year alkali waste and furnace slag were used in manufacture of Portland cement. In 1889, 80 per cent. of the cement in this country was burned in stationary kilns, while in 1901, 93 per cent. was burned in rotary kilns.

The rotary kiln illustrated in plate XXIX. is a slightly inclined steel cylinder usually about 60 feet long and 6 to 7 feet in diameter, lined with fire brick, and revolving on rollers at a rate of one revolution in from one to three minutes. The kilns are made of uniform diameter throughout or with a tapering portion into the chimney. The inclination is three to four feet in sixty. The kiln is supported on the rollers at two points and is revolved by a train of gearing. The discharge end of the kiln is covered by a brick head supported on four wheels which rest on a track enabling the head to be removed and give access to the interior.

While 60 feet represents the standard length and 6 feet the standard width of kiln, they have been made as short as 45 feet. At the Edison plant in New Jersey the length of kiln is 150 feet, diameter 9 feet, and sixteen kilns of this size have recently been installed in the new cement plant at Hull, Canada.

The 60 foot kiln will produce about 150 barrels of cement a day, using 120 pounds of coal to the barrel. The large kilns at Hull are said to yield 750 barrels a day, with fuel consumption of 75 pounds to the barrel. The shorter length of kiln requires the high temperature through the kiln and the products of combustion pass out the stack carrying considerable heat which is thereby lost. The longer kiln requires a larger amount of power and it is a matter of dispute whether sufficient advantage is secured in the increased length.

The kilns are lined with fire brick which must be hard burned to stand the abrasion. High silica brick are said to flux with the cement clinker at high temperature used. According to Lathbury and Spackman,¹ the best results will be given by the use of fire brick whose composition falls in the following limits:

Silica	45.00 to 50.00	per cent.
Alumina	0.50 to 48.00	" "
Ferric iron.....	0.50 to 3.00	" "
Lime oxide.....	0.10 to 0.50	" "
Magnesia oxide.....	trace to 0.35	" "

1. Rock Products, Vol. 1, No. 9, p. 9.

The material is fed by screw conveyor into the stack end of the kiln, and passes out at the other end as a clinker, varying in size up to two or three inches in diameter, into cooling bins below or into elevators carrying it to cooling bins or towers. The fuel most commonly used is a pulverized coal which is fed by an air blast through a pipe passing through the brick head of the kiln.

Heating of the Kiln.—Theoretically heat enough is required in the kiln to drive off any moisture present, to drive off the carbonic dioxide (CO_2) from the limestone, marl, or chalk and produce the chemical combination of the lime and alumina, lime and silica.

According to Eckels¹ heat for these changes would theoretically be furnished by $25\frac{1}{2}$ pounds of good coal, to the barrel of cement. Under average conditions of moisture, 43 pounds of coal to the barrel of cement have been given as theoretically required.

Practically this amount of coal has been found insufficient for four reasons.

1. The radiation of heat from the kiln wall.
2. The gases of combustion escape to the stack carrying a certain amount of heat.
3. The clinker discharged hot, removes a large amount of heat.
4. The air supply for combustion is greater than actually required for perfect combustion, thus lowering the heating value of the fuel.

The best result is stated to be about 60 pounds of coal to the barrel of cement. The average results would be about 180 pounds of coal to the barrel of cement in the wet process, and 120 pounds in the dry process, to which should be added 70 pounds for power in the different parts of the manufacture.

The heating power of coal is usually expressed in calories or British thermal units (B. T. U.). The calorie equals the number of kilograms of water which one kilogram of fuel will raise 1° centigrade. The British thermal unit equals the number of pounds of water, one pound of fuel will raise 1° Fahrenheit. One calorie equals 4 B. T. U.

1. Geol. Survey of Alabama, Bull. 8, p. 52.

The number of heat units in a coal may be calculated from the proximate analysis of a coal by the following formula given by Haas in Volume II (p. 216) of this series of reports.

$$B. T. U.=H [100-(\text{Ash}+\text{Sulphur}+\text{Moisture})]+\text{Sulphur}\times 4050$$

The constant "H" is determined by method given in Volume II (page 217) and for the Fairmont coal group equals 15675. This figure would vary in different coals.

To illustrate this method, a certain coal supposed by the owners to be adapted to cement work has a composition, where "H" equals 15766.

Fixed carbon.....	68.18	per cent.
Volatile matter.....	24.81	" "
Moisture	0.93	" "
Ash	6.08	" "
Sulphur	0.48	" "

$$B. T. U.=15766 [100(-6.08+0.48+0.93)]+0.48\times 4050=14778.$$

This coal has high heating value, as the average of the Fairmont coals is 14120, but it is low in volatile matter, the average of Fairmont coals being 36.96 per cent.

A coal for fuel in rotary kilns should have, according to Lathbury and Spackman, 40 to 50 per cent. of fixed carbon, and over 25 per cent. of volatile matter. Other engineers insist on a higher percentage of volatile matter, at least over 30 per cent.

Distribution of Heat in Kiln.—Very careful measurements were made by Prof. J. W. Richards¹ on the heat generated in a rotary kiln 60 feet long and 6 feet diameter. The coal used was from Fairmont and required 110 pounds of coal to the barrel of cement (380 pounds). The average amount of clinker was 3635 pounds per hour from 5980 pounds of mixture, at the same time producing 200 pounds of flue dust. The temperature of the clinker as discharged was 1200° C. (2192° F.), and the temperature of the waste gases in the stack was 820° C. (1508° F.).

The heat generated in the kiln is due to the heat developed by the fuel and the heat developed by the chemical combination of the ingredients in forming the clinker. The results of Professor Richards' investigation are given in the following table:

1. Jour. Amer. Chem. Soc. Vol. XXVI., No. 1, p. 80; 1904.

HEAT GENERATED

	Calories.
1. Theoretical heating power of the fuel.....	790,000
2. Heat of combination of ingredients forming clinker.....	142,819
Total.....	932,819

HEAT DISTRIBUTION.

	Calories.	Percentage of whole.
1. Heat in the hot clinker.....	100,050	10.7
2. Heat in the chimney gases:		
a. In the excess air admitted.....	336,000	36.0
b. In the necessary products.....	340,000	36.1
3. Heat in the flue dust.....	2,112	0.2
4. Loss by imperfect combustion.....	12,248	1.3
5. Evaporation of water of charge.....	1,446	0.2
6. Expulsion of carbon dioxide from carbonates	21,628	2.3
7. Loss by radiation and conduction.....	119,335	12.8
	932,819	

The heat due to chemical combination is 18 per cent. of heat developed by combustion of the coal. The temperature formed by the fuel in the kiln is about 1000° C., while the clinker leaves the kiln at 1200° C. and had probably a higher temperature in the kiln.

The heat of chemical combination for the lime with silica or alumina is 591 calories per kilogram of lime (Berthelot) and 827 calories per kilogram of magnesia. The heat in the clinker is 10.7 per cent. of the total amount developed in the kiln, representing a loss of nearly 90 per cent. of heat in this kiln.

The amount of heat lost through the escaping gases and excess of air is nearly three-fourths of the total heat developed or over 85 per cent. of the calorific value of the fuel. Professor Richards suggests that if a kiln was used with twice the length, the temperature of the gases would be reduced one-half, and if the amount of air excess could be reduced to 10 per cent. the saving in amount of fuel might reach 60 per cent. In the 150 foot kilns at Hull, Canada, mentioned above, 75 pounds of coal are used to the barrel of cement, which would represent a saving of 32 per cent. in fuel over the kiln tested by Professor Richards.

The amount of air admitted in the kiln tested was 132 per cent. in excess of amount theoretically required for perfect combustion of the fuel. It is thus seen that the rotary kiln as used at the present time is very wasteful of heat and therefore of fuel.

A little over 10 per cent. of the total heat being used in forming the clinker.

A comparison with the other types of kilns is given by Lewis in the following tables:¹

Fuel required.	Per cent. fuel.
Intermittent kilns require.....	25 to 35 (Coke)
Continuous shaft kilns require.....	12 to 16 (Coal)
Rotary kilns require.....	30 to 40 (Coal)

COST PER BARREL.

	Rotary kiln.	Continuous shaft kiln.
For labor.....	2½ to 4 cents	12 to 14 cents
For fuel.....	11 to 15 cents	5 to 6 cents

DAILY PRODUCTION.

Intermittent kilns.....	15 to 30 barrels.
Continuous shaft kilns.....	40 to 80 "
Rotary kilns.....	120 to 150 "

While the rotary kiln is wasteful of fuel, it shows a great saving in labor and a marked increase in daily capacity, and by further improvements the cost of fuel will be decreased.

Temperature of Burning.—The proper degree of burning is indicated by the formation of a dense greenish-black clinker. Underburned clinker is brownish and soft, while the overburned clinker is fused and slag-like. Long continued burning or excess of clay causes the clinker to dust or fall to powder on cooling with practically no hydraulic properties.

The temperature to be used in the rotary kiln will vary with the materials and mixtures used but is about 1200° to 1400° C. (2192° to 2552° F.)

According to Prof. E. D. Campbell,² the minimum temperature to produce Portland cement that will give a perfect pat test from fresh clinker, is 1450° C. (2642° F.) for a minimum of lime. It will increase with the lime percentage and in ordinary commercial cements the temperature is about 1550° C. (2822° F.) Slow driving of the rotary kiln tends to lower this temperature. Lean clays heavily limed have a wide margin between proper clinkering and overburning, while in rich clays great care is required. If overburned the clinker adheres together and to the sides of the kiln.

1. Cement Industry, Eng. Record, p. 188.

2. Jour. Amer. Chem. Soc. Vol. XXIV., p. 969; 1902.

Mr. Richard K. Meade has made some careful tests on the changes that take place in the clinkering of the Lehigh Valley cement rock.¹ Samples of the raw material, clinker and coal were taken at frequent intervals and analyzed. A comparison of the composition of the raw material and the clinker shows the following changes:

1. A loss of practically all the carbon dioxide, carbon and water.
2. Almost complete oxidation of the iron present in the raw material in the ferrous condition.
3. A large loss of sulphur and the almost complete oxidation of the remainder. Therefore coals high in sulphur if otherwise of the correct composition can be used without injury to the resulting product.
4. Over one-half the alkalies, potash and soda, present in the original rock were expelled in the kiln.
5. Apparently there is no loss of titanite oxide phosphoric oxide, or manganese.

Mr. Meade further finds a marked loss of material as dust during the pulverizing and burning of the raw material and clinker. If there was no such loss, and the raw materials had 5 per cent. of moisture, it would require 583 pounds of raw materials to make a barrel of cement (380 pounds) but he states that few manufacturers use less than 610 pounds, showing a loss of 27 pounds as dust, etc., per barrel of cement produced.

Fuel Supply in West Virginia.—The distribution, thickness, chemical composition, and heating value of the coals of West Virginia are discussed in detail in volume II. of the reports of this series. In selecting a coal for cement work this volume should be carefully studied.

Coal for cement burning, as has been stated, must have a high heating power, high percentage of volatile matter, low sulphur content, and a low ash percentage, not over 9 or 10 per cent. Lower grade coals may be used for the boilers and driers.

A few illustrations are selected from volume II. showing the composition of some coals in the State adapted to the burning of the cement clinker. Reference to this volume will show other coals adapted to this work.

1. The Chem. Engineer, Vol. II., No. 4, p. 221.

Geological Horizon.	Location.	Thickness. Feet.	Moisture.	Volatile matter.	Fixed carbon.
Sewickley	Sturm's Mills....	5½	1.43	38.67	51.21
Redstone	Century	6	0.67	36.21	54.38
Pittsburg	Fairmont	8½	1.62	36.70	54.44
Pittsburg	Fairmont	9	1.49	36.96	54.77
Upper Freeport	Decker's Creek...	6	1.55	30.97	59.95
Stockton	Thacker	8	0.41	36.33	58.09
Coalburg	Mammoth	4½	0.56	36.63	56.38
Winifrede	Lens creek.....	5	0.65	37.06	56.70
Cedar Grove	Monarch	3	0.69	35.92	59.24
Campbells Creek	Blacksburg	5	0.73	34.70	59.82
Brownstown	Trace Fork.....	4	0.26	36.27	56.82

Geological Horizon.	Location.	Ash.	Sulphur.	British Thermal Units.	Remarks.
Sewickley	Sturm's Mills.	8.69	4.42		
Redstone	Century	8.74	2.90	12,314	
Pittsburg	Fairmont	7.15	1.94	14,076	Enterprise mine Ave. 20 mines. Low in volatile.
Pittsburg	Fairmont	6.78	2.23	14,120	
Upper Freeport	Decker's creek	7.53	0.89	14,068	
Stockton	Thacker	5.17	0.86	14,738	
Coalburg	Mammoth	6.43	0.51	13,855	
Winifrede	Lens creek....	5.59	0.65	14,543	
Cedar Grove	Monarch	4.15	0.58	14,693	
Campbells Creek	Blacksburg ..	4.72	1.18	14,715	
Brownstown	Trace Fork...	6.65	1.72		

Natural gas fuel is available in the central and eastern portions of the State. It has been estimated that 20,000 cubic feet of gas are equivalent in heating power to one ton of good coal.

Natural gas in West Virginia is described in volumes I. and I-a of this series. It is there shown that the heat generated by natural gas combustion is due especially to the paraffines, ethane (C_2H_6) and methane (CH_4).

The proportion of paraffines and the heating power of the gas in several fields are shown in the following table from volume I-a.

The rolls are pressed by the springs against the rock on the ring with a pressure adjustable to 20,000 pounds. The crushed rock passes from each side of the ring into the casing and through an outlet pipe. 90 per cent. of the rock is claimed to be abraded on itself in crushing so that wear on the parts of the machine is slight. The Kent mill is illustrated in figure 38. The speed is 180 revolutions per minute, and capacity with limestone about eight tons per hour, requiring 25 H. P.

The Raymond impact pulverizer is a roller mill with the rollers revolving around a central upright shaft, and an air separator attached which draws the material from the rolls as it is ground and separates it into fine powder, returning the coarse tailings to the mill for further grinding. It is claimed by the company to do the work of a ball and tube mill combined with one-half the horse power.

Ball Mill.—The ball mill was originally designed and used for reducing materials from lump state to the proper fineness in one operation. This method required the use of outside fine screens which for cement work where extreme fineness is required, gave small capacity and caused much difficulty in keeping the fine screens open. Yet with these disadvantages it proved more economical than the use of millstones.

After the invention of the tube mill, the ball mill was used for preliminary crushing only, its product passing through a 30 mesh screen goes to the tube mill for fine grinding.

Steel balls, two to five inches in diameter, are placed in the mill, and by their movement grind and crush the material. The capacity of the mill is estimated at 100 per cent. per ton of balls.

The ball mill consists of two circular side plates provided with inwardly projecting and eccentrically located shelves. The side plates have attached to them rigidly at their centers hubs, which are mounted on a heavy shaft. The Gates ball mill is shown in figures 39 and 41.

Resting upon the inwardly projecting shelves and reaching from one side plate to the other are the wearing plates which are eccentrically arranged so that one plate passes behind the next one, thus producing a step and also providing an opening through which residues from the screens are returned to the mill. The tumbling of the balls and material due to revolving the drum rapidly reduces the material to a fine grit and powder, the steps

carrying the balls upward so as to fall from an elevation on the material, increases the grinding effect.

When partially reduced, the ground product falls through apertures in the wearing plates to the first screen. The tailings from the screen are promptly returned to the mill through the

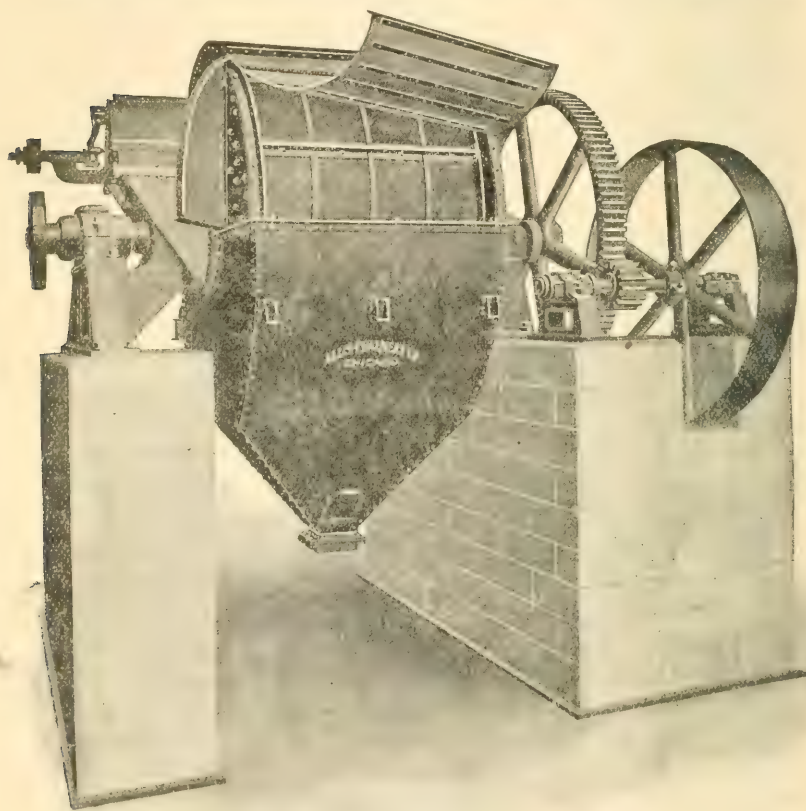


Fig. 39.—Gates Ball Mill with Feeder.

openings between the overlapping plates. The screened material falls upon the second screen and the tailings from it are returned to the mill while the fine material goes to the outside finishing screen and the part going through falls into the dust proof hous-

ing and is removed by conveyor for final grinding. The residues in all cases are returned to the mill for further grinding.

The highest efficiency in the ball mill is to be obtained by constant and regular feeding. It is almost impossible for a workman to control the inflow of material in any regular manner. This is usually accomplished by an automatic machine feeder, consisting of a revolving plate on which the material falls and a scraper which throws a sufficient stream of material into the mill, in the Smidth pattern, and by a swinging ball feeder made adjustable in the Gates mill.

DETAILS OF GATES BALL MILL.

Size.	Weight with- out balls.	Weight of charge of balls.	Capacity on Portland cement clinker to 20 mesh.	H. P. required.
7	29,500 lbs.	3000 lbs.	12 to 16 bbls. per hr.	30 to 40
8	41,100 lbs.	4500 lbs.	18 to 24 bbls. per hr.	40 to 50

From 100 to 120 per cent. additional power is required momentarily in starting these machines. When pulverizing to pass through 20 mesh screen, from 30 to 40 per cent. will pass a 100 mesh sieve.

Kominuter.—This machine as made by Smidth & Company is a modified ball mill made in a cylindrical barrel form and so arranged that the material from the inlet end travels to the opposite end across a solid instead of a perforated plate, and the screen is thus protected from the action of the balls. The material then travels back to the inlet end over a conical screen. A larger charge of balls can be used, reaching 6,600 pounds, the discharge openings are not subjected to impact of the balls, and the machine is claimed to give a much larger capacity with same power and size than the regular ball mill. The Smidth kominuter is shown in figure 40.

Tube Mill.—The tube or pebble mill consists of a wrought iron tube mounted as a shaft by the attachment of dome shaped ends which rest in bearings. The tube is lined with chilled iron, or stone silex, and is about half filled with hard flint pebbles. The shaft at the feed end is hollow and a screw conveyor carries in the material, and it is delivered ground at the opposite end.

The Bonnot tube mill is illustrated in figure 41-a, and the Smidth tube mill in plate XXXI.

The pebbles are imported from northern Europe where there are abundant deposits of very hard pebbles. Four sizes, 2 to 1¼ inches in diameter, are charged into the mill, and as they wear

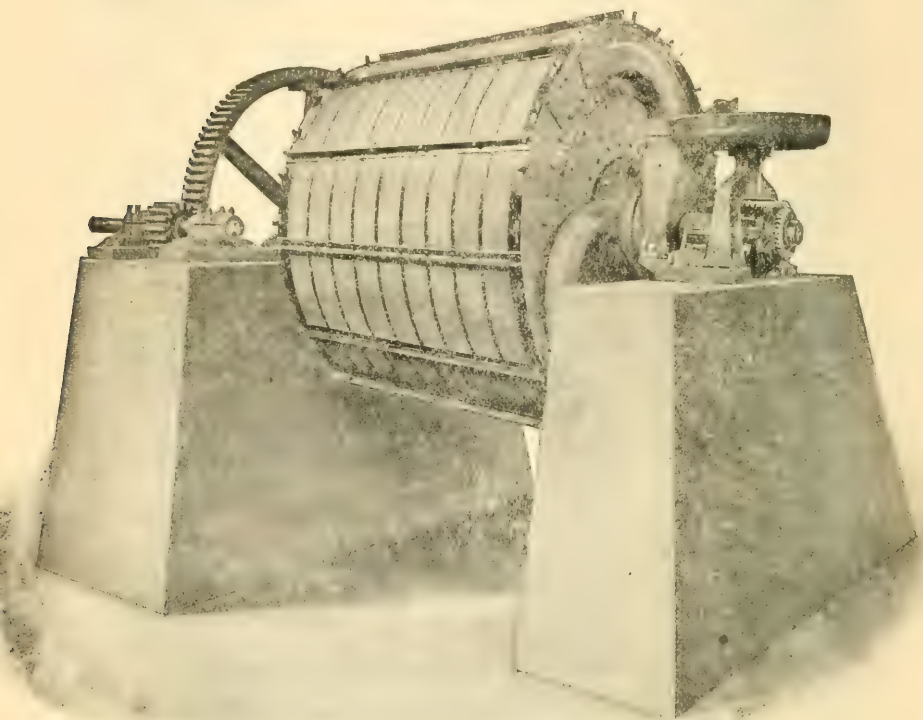


Fig. 40.—Smidth Kominuter for Grinding Cement.

down are replaced with the larger size. When used in grinding of clinker they wear on an average of one pound to 30 barrels of cement. The pebbles cost about \$25 per 1000 kilograms (2204) pounds.

The common size of tube mill is 22 feet long and 5 feet in diameter. This size will grind about 6 tons of raw material per hour, or of clinker about 14 to 20 barrels an hour, requiring 70 to 80 horse power. The mill is run at low speed. The velocity at

which the tube revolves tends to carry the mixture of pebbles and material to a certain height in the mill from which point pebbles and material fall together with rolling and grinding as they fall to the bottom of the mill.

The exact grinding action in a tube mill has been recently studied in detail by use of experimental glass mills by Fischer. The following facts were observed on an experimental mill three feet in diameter as quoted in the Ohio Survey volume on cement.¹

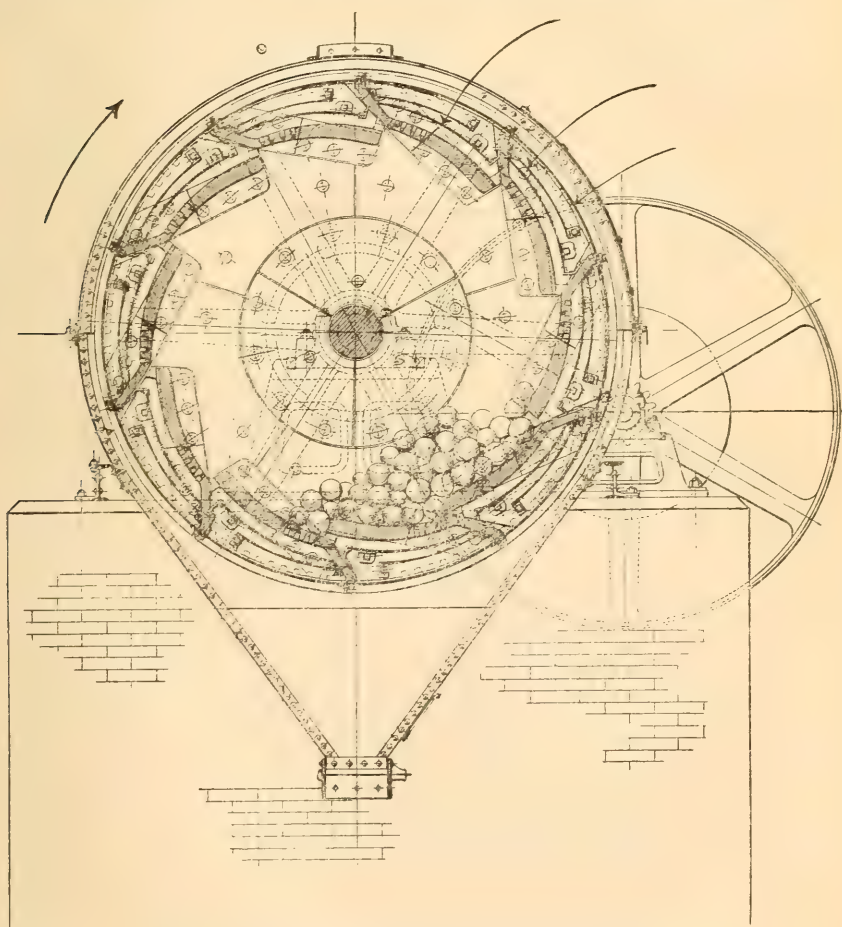


Fig. 41.—Gates Ball Mill—Sectional View.

1. Zeitschrift des Vereins Deutscher Ingenieure No. 13, 1904. Quoted in Ohio Geol. Survey, Bull. 3, p. 274.

"When at rest the pebbles showed a height of 450 mm. The mill was now rotated with a speed of $23\frac{1}{2}$ revolutions per minutes, and it was found that the pebbles rolled down the side rather slowly. On increasing the speed the pebbles seemed to loosen, and they rose to a height of 600 mm. with 32 revolutions. The pebbles have no motion until they are carried up the side of the mill, when at a certain height they become loose and drop back to the bottom, describing a curvilinear path which can be noticed quite distinctly. The pebbles farther away from the surface also do not move with reference to the circumference up to a certain height, but their downward path is more difficult to recognize. On increasing the speed to 35 revolutions the content of the cylinder is loosened still more, so that the pebbles rise to a height of 650 mm.; the downward path becomes quite distinct, and the lower pebbles separate in distinct layers. The pebbles of one layer do not mix with pebbles from the other layers. On speeding up the mill still more, the pebbles at 55 revolutions form a solid ring around the circumference, without any displacement of the balls.

"When material is to be ground it assumes the same motion as the pebbles, distributing itself within the spaces so that it is densest where the latter are loose. No rubbing and rolling between pebbles and the charge takes place anywhere except at the point where the pebbles strike the surface on falling from the highest point. The pebbles climbing up the side of the mill drop away from it as soon as the vertical component of the forces acting upon it is equal to the centrifugal force.

"The grinding effect depends on the vertical distance of the drop, the velocity of the drum, and weight and number of the pebbles."

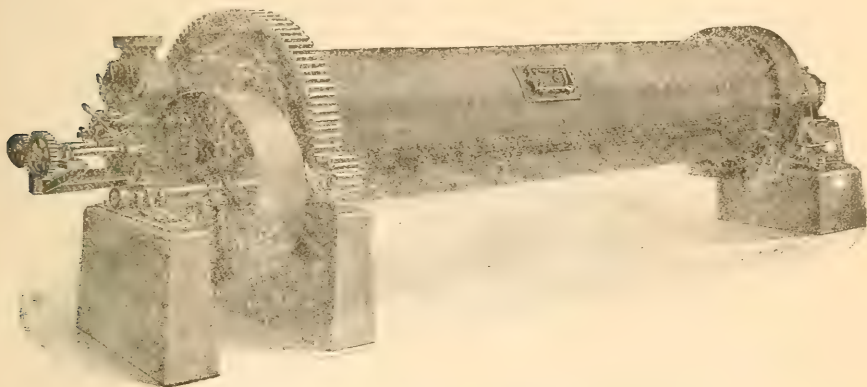
Cause of forward movement of the material in the mill: "As the pebbles descend from their highest point and strike the material to be ground the latter is splashed quite a distance, and if there is much material present, a good deal will thus be distributed, while places where there is little throw off but a small amount. In this manner the material is distributed uniformly. This equalization takes place rapidly, as the velocity of the pebbles is quite great, being often as great as the circumferential velocity of the mill. At the exit the ground material is thrown out through the grating, while the pebbles are retained."

SEMI-DRY AND WET MIXTURES.

In the Iola, Kansas plants the limestone and shale are crushed in Gates crushers, dried in rotary driers, reduced in Griffin mills and mixed with 30 per cent. water in agitator tanks, then burned in rotary kilns.

The agitators are large steel tanks with a central shaft and revolving arms which thoroughly mix the slurry. Analyses are made of the material in the tanks and more limestone or shale added as required. The slurry after thorough mixture is ready for the kilns. This method gives a complete control over the lime and shale mixture and has been very successful in these plants. The semi-dry method is a popular one in a number of English mills.

In the wet method as used in the marl plants of Michigan, the slurry is made with 60 per cent water, and usually there is no preliminary drying of the materials.



6. *BURNING OF THE CEMENT MIXTURE.*

Four types of kilns are used in burning Portland cement :

1. Dome kilns, intermittent, similar to lime kilns.
2. Continuous kilns, of Dietzsch and Schoefer types.
3. Hoffman ring kiln.
4. Rotary kiln.

Dome Kiln.—Dome kilns of the lime kiln pattern are 25 to 35 feet high, tapering to the base, and 10 to 18 feet in diameter, made of stone, brick or iron. They are usually found in the natural cement plants where the fuel and rock are added in alternate layers, the burned product being removed below and new material added at the top.

The early Portland cement kilns¹ were constructed on a similar plan except the operation was intermittent. Wood and coke were piled for several feet above the grate then dried slurry and coke in alternate layers to the doors near the top of the kiln, which were sealed shut after filling the kiln. The fires were started and allowed to burn through the clinker formed to the top, when the kiln was opened, the clinker discharged and the operation repeated. It required 7 to 10 days to fill and burn the kiln, giving a capacity of three to six tons of cement a day. A row of dome kilns is shown in plate XXVII-b.

1. Lewis, *Mineral Industry*, Vol. VI., p. 106.

The method was expensive in fuel and required considerable labor in sorting the clinker to remove the under and over-burned material. This type of kiln was used for the manufacture of Portland cement in this country until replaced by the rotary kiln in 1889. These dome kilns are still used by some small foreign plants, but they have practically disappeared in Portland cement manufacture. The Johnson kiln as a modified dome kiln is in common use in England. This is an intermittent kiln with long horizontal drying flues between the kiln and chimney. The wet slurry is dried in these flues by the products of combustion of one charge, and the kiln is recharged by taking the dried slurry from the flues and placing it in the kiln with alternate layers of coke.

Dietzsch Kiln.¹—This type of kiln was patented in 1884, and first used in 1886. It is one of the common type of kilns in German cement mills and found in a few American plants. The kiln is continuous in its action. The dried slurry is charged into the chimney near the top and the clinker drawn at the bottom. The upper and lower parts of the stack are separated by the fire bridge, and just below is the combustion chamber, five or six feet deep.

In the chimney above the fire bridge the raw material is heated, and in the shaft below, the clinker is cooled. When the clinker is removed, the mass of slurry briquettes settles to the fire bridge. The slurry is here pulled across the bridge by long handled iron bars thrust through the fire doors, and fills the combustion chamber with the fuel added in sufficient quantity.

The fuel is a powdered coal high in volatile matter so that the flame passes over the fire bridge and up the chimney. The bricks of slurry in the chimney are thus gradually heated and by the time they reach the fire bridge are red hot. They are clinkered in the combustion chamber and cooled by air in the cooling compartment so that the clinker can be readily handled.

The amount of fuel required is smaller than in many other types, but the slurry is dried by artificial heat before it is fed into the kiln, which requires an additional amount of fuel. The labor cost is greater than in the other types, and there is said to be considerable waste in the clinker through under-burning.

Schoefer Kiln.—This type is a modified Dietzsch kiln where the fire bridge is replaced by a narrowed zone above the fire holes.

1. Lewis, Cement Industry, Eng. Record, p. 226.

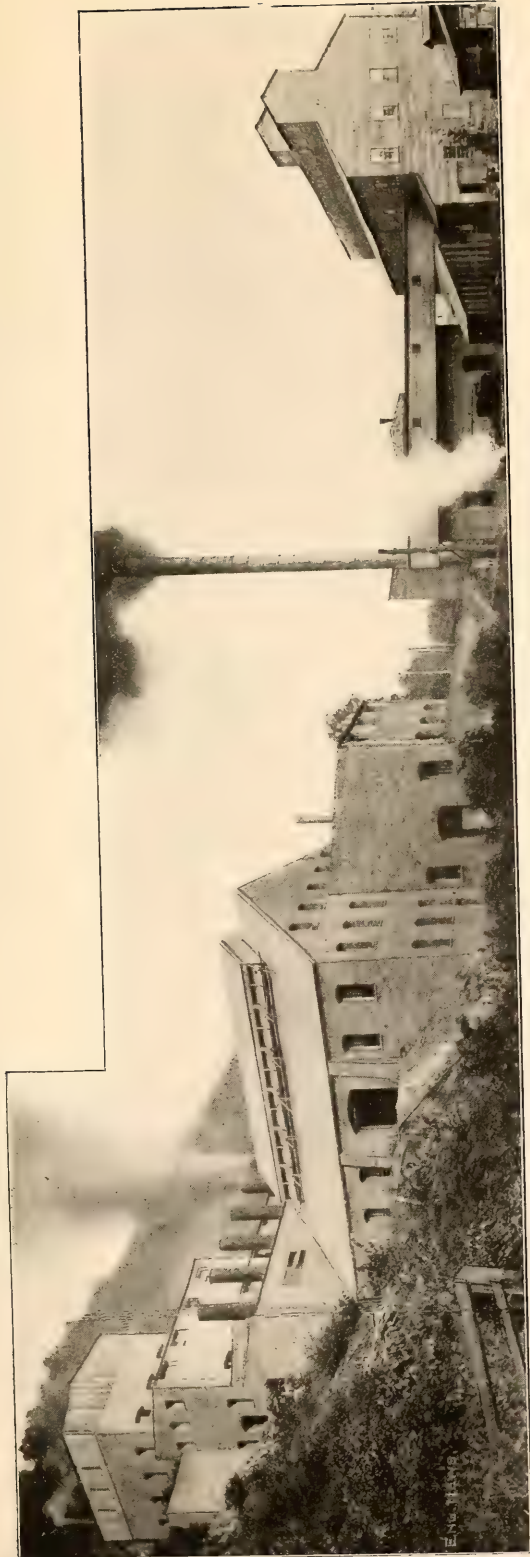


Plate XXXV.—General View of the Buildings of the Buckhorn Portland Cement Co.

Hoffman Ring Kiln.¹—This kiln was originally used in Germany for burning brick. It consists of a continuous gallery of an elliptical shape built around a central chimney. There are usually 15 or 20 compartments with as many entrances from the outside, and as many ports leading into the chimney. In practical working in a kiln of 20 compartments there are, perhaps, six filled with burned clinker, two in process of burning, six filled with bricks of slurry not yet burned.

The connection with the chimney is by the port in the last chamber filled with slurry bricks, and the draft is through the open door of the compartment on the other side which is being discharged of clinker. All other openings to the chimney and to outside are closed. The air is heated by passing through the hot clinker in six chambers and arrives at a high temperature in the combustion chamber. The products of combustion then pass through several chambers filled with bricks to be burned, which are thus heated to a high temperature before burning begins. About one ton of coal is required to produce 6½ tons of clinker. These kilns are used in some of the largest German plants and in a few American mills.

Rotary Kiln.—Probably three-fourths of the American Portland cement is burned in rotary kilns. This type of kiln in its essential features was patented by Siemens in 1869, and adapted to cement manufacture, using producer gas in a patent given to Ransome in England in 1885, and in the United States in 1886.² Its use in England was attended by a series of failures and at the present time it is found in very few foreign mills, but as improved and developed in the United States, it has become the most common form of cement kiln.

The first use of the rotary kiln in this country was by the Atlas Portland Cement Company in 1886 at their plant at Roundout on the Hudson river, and later in the Coplay district, Pennsylvania. From 1892-'96 oil was used as fuel in preference to gas and proved to be cheaper. After that time powdered coal was substituted.³

According to Lathbury and Spackman, the first burning of pulverized limestone and clay in rotary kilns was in 1898, and in

1. Lewis, Cement Industry, Eng. Record, p. 219.

2. Lewis in Cement Industry, Eng. Record, p. 188.

3. Lewis, loc. cit., p. 190.

the same year alkali waste and furnace slag were used in manufacture of Portland cement. In 1889, 80 per cent. of the cement in this country was burned in stationary kilns, while in 1901, 93 per cent. was burned in rotary kilns.

The rotary kiln illustrated in plate XXIX. is a slightly inclined steel cylinder usually about 60 feet long and 6 to 7 feet in diameter, lined with fire brick, and revolving on rollers at a rate of one revolution in from one to three minutes. The kilns are made of uniform diameter throughout or with a tapering portion into the chimney. The inclination is three to four feet in sixty. The kiln is supported on the rollers at two points and is revolved by a train of gearing. The discharge end of the kiln is covered by a brick head supported on four wheels which rest on a track enabling the head to be removed and give access to the interior.

While 60 feet represents the standard length and 6 feet the standard width of kiln, they have been made as short as 45 feet. At the Edison plant in New Jersey the length of kiln is 150 feet, diameter 9 feet, and sixteen kilns of this size have recently been installed in the new cement plant at Hull, Canada.

The 60 foot kiln will produce about 150 barrels of cement a day, using 120 pounds of coal to the barrel. The large kilns at Hull are said to yield 750 barrels a day, with fuel consumption of 75 pounds to the barrel. The shorter length of kiln requires the high temperature through the kiln and the products of combustion pass out the stack carrying considerable heat which is thereby lost. The longer kiln requires a larger amount of power and it is a matter of dispute whether sufficient advantage is secured in the increased length.

The kilns are lined with fire brick which must be hard burned to stand the abrasion. High silica brick are said to flux with the cement clinker at high temperature used. According to Lathbury and Spackman,² the best results will be given by the use of fire brick whose composition falls in the following limits:

Silica	45.00 to 50.00	per cent.
Alumina	0.50 to 45.00	" "
Ferrie iron.....	0.50 to 3.00	" "
Lime oxide.....	0.10 to 0.50	" "
Magnesia oxide.....	trace to 0.35	" "

The material is fed by screw conveyor into the stack end of the kiln, and passes out at the other end as a clinker, varying in size up to two or three inches in diameter, into cooling bins below or into elevators carrying it to cooling bins or towers. The fuel most commonly used is a pulverized coal which is fed by an air blast through a pipe passing through the brick head of the kiln.

Heating of the Kiln.—Theoretically heat enough is required in the kiln to drive off any moisture present, to drive off the carbonic dioxide (CO_2) from the limestone, marl, or chalk and produce the chemical combination of the lime and alumina, lime and silica.

According to Eckels¹ heat for these changes would theoretically be furnished by $25\frac{1}{2}$ pounds of good coal, to the barrel of cement. Under average conditions of moisture, 43 pounds of coal to the barrel of cement have been given as theoretically required.

Practically this amount of coal has been found insufficient for four reasons.

1. The radiation of heat from the kiln wall.
2. The gases of combustion escape to the stack carrying a certain amount of heat.
3. The clinker discharged hot, removes a large amount of heat.
4. The air supply for combustion is greater than actually required for perfect combustion, thus lowering the heating value of the fuel.

The best result is stated to be about 60 pounds of coal to the barrel of cement. The average results would be about 180 pounds of coal to the barrel of cement in the wet process, and 120 pounds in the dry process, to which should be added 70 pounds for power in the different parts of the manufacture.

The heating power of coal is usually expressed in calories or British thermal units (B. T. U.). The calorie equals the number of kilograms of water which one kilogram of fuel will raise 1° centigrade. The British thermal unit equals the number of pounds of water, one pound of fuel will raise 1° Fahrenheit. One calorie equals 4 B. T. U.

1. Geol. Survey of Alabama, Bull. 8, p. 52.

The number of heat units in a coal may be calculated from the proximate analysis of a coal by the following formula given by Haas in Volume II (p. 216) of this series of reports.

$$B. T. U.=H [100-(\text{Ash}+\text{Sulphur}+\text{Moisture})]+\text{Sulphur}\times 4050$$

The constant "H" is determined by method given in Volume II (page 217) and for the Fairmont coal group equals 15675. This figure would vary in different coals.

To illustrate this method, a certain coal supposed by the owners to be adapted to cement work has a composition, where "H" equals 15766.

Fixed carbon.....	68.18	per cent.
Volatile matter.....	24.81	" "
Moisture	0.93	" "
Ash	6.08	" "
Sulphur	0.48	" "

$$B. T. U.=15766 [100(-6.08+0.48+0.93)]+0.48\times 4050=14778.$$

This coal has high heating value, as the average of the Fairmont coals is 14120, but it is low in volatile matter, the average of Fairmont coals being 36.96 per cent.

A coal for fuel in rotary kilns should have, according to Lathbury and Spackman, 40 to 50 per cent. of fixed carbon, and over 25 per cent. of volatile matter. Other engineers insist on a higher percentage of volatile matter, at least over 30 per cent.

Distribution of Heat in Kiln.—Very careful measurements were made by Prof. J. W. Richards¹ on the heat generated in a rotary kiln 60 feet long and 6 feet diameter. The coal used was from Fairmont and required 110 pounds of coal to the barrel of cement (380 pounds). The average amount of clinker was 3635 pounds per hour from 5980 pounds of mixture, at the same time producing 200 pounds of flue dust. The temperature of the clinker as discharged was 1200° C. (2192° F.), and the temperature of the waste gases in the stack was 820° C. (1508° F.).

The heat generated in the kiln is due to the heat developed by the fuel and the heat developed by the chemical combination of the ingredients in forming the clinker. The results of Professor Richards' investigation are given in the following table:

1. Jour. Amer. Chem. Soc. Vol. XXVI., No. 1, p. 80; 1904.

HEAT GENERATED

Calories.

1. Theoretical heating power of the fuel.....	790,000
2. Heat of combination of ingredients forming clinker.....	142,819
Total.....	932,819

HEAT DISTRIBUTION.

	Calories.	Percentage of whole.
1. Heat in the hot clinker.....	100,050	10.7
2. Heat in the chimney gases:		
a. In the excess air admitted.....	336,000	36.0
b. In the necessary products.....	340,000	36.1
3. Heat in the flue dust.....	2,112	0.2
4. Loss by imperfect combustion.....	12,248	1.3
5. Evaporation of water of charge.....	1,446	0.2
6. Expulsion of carbon dioxide from carbonates	21,628	2.3
7. Loss by radiation and conduction.....	119,335	12.8
	932,819	

The heat due to chemical combination is 18 per cent. of heat developed by combustion of the coal. The temperature formed by the fuel in the kiln is about 1000° C., while the clinker leaves the kiln at 1200° C. and had probably a higher temperature in the kiln.

The heat of chemical combination for the lime with silica or alumina is 591 calories per kilogram of lime (Berthelot) and 827 calories per kilogram of magnesia. The heat in the clinker is 10.7 per cent. of the total amount developed in the kiln, representing a loss of nearly 90 per cent. of heat in this kiln.

The amount of heat lost through the escaping gases and excess of air is nearly three-fourths of the total heat developed or over 85 per cent. of the calorific value of the fuel. Professor Richards suggests that if a kiln was used with twice the length, the temperature of the gases would be reduced one-half, and if the amount of air excess could be reduced to 10 per cent. the saving in amount of fuel might reach 60 per cent. In the 150 foot kilns at Hull, Canada, mentioned above, 75 pounds of coal are used to the barrel of cement, which would represent a saving of 32 per cent. in fuel over the kiln tested by Professor Richards.

The amount of air admitted in the kiln tested was 132 per cent. in excess of amount theoretically required for perfect combustion of the fuel. It is thus seen that the rotary kiln as used at the present time is very wasteful of heat and therefore of fuel.

A little over 10 per cent. of the total heat being used in forming the clinker.

A comparison with the other types of kilns is given by Lewis in the following tables:¹

Fuel required.	Per cent. fuel.
Intermittent kilns require.....	25 to 35 (Coke)
Continuous shaft kilns require.....	12 to 16 (Coal)
Rotary kilns require.....	30 to 40 (Coal)

COST PER BARREL.

	Rotary kiln.	Continuous shaft kiln.
For labor.....	2½ to 4 cents	12 to 14 cents
For fuel.....	11 to 15 cents	5 to 6 cents

DAILY PRODUCTION.

Intermittent kilns.....	15 to 30 barrels.
Continuous shaft kilns.....	40 to 80 "
Rotary kilns.....	120 to 150 "

While the rotary kiln is wasteful of fuel, it shows a great saving in labor and a marked increase in daily capacity, and by further improvements the cost of fuel will be decreased.

Temperature of Burning.—The proper degree of burning is indicated by the formation of a dense greenish-black clinker. Underburned clinker is brownish and soft, while the overburned clinker is fused and slag-like. Long continued burning or excess of clay causes the clinker to dust or fall to powder on cooling with practically no hydraulic properties.

The temperature to be used in the rotary kiln will vary with the materials and mixtures used but is about 1200° to 1400° C. (2192° to 2552° F.)

According to Prof. E. D. Campbell,² the minimum temperature to produce Portland cement that will give a perfect pat test from fresh clinker, is 1450° C. (2642° F.) for a minimum of lime. It will increase with the lime percentage and in ordinary commercial cements the temperature is about 1550° C. (2822° F.) Slow driving of the rotary kiln tends to lower this temperature. Lean clays heavily limed have a wide margin between proper clinkering and overburning, while in rich clays great care is required. If overburned the clinker adheres together and to the sides of the kiln.

1. Cement Industry, Eng. Record, p. 188.

2. Jour. Amer. Chem. Soc. Vol. XXIV., p. 969; 1902.

Mr. Richard K. Meade has made some careful tests on the changes that take place in the clinkering of the Lehigh Valley cement rock.¹ Samples of the raw material, clinker and coal were taken at frequent intervals and analyzed. A comparison of the composition of the raw material and the clinker shows the following changes:

1. A loss of practically all the carbon dioxide, carbon and water.
2. Almost complete oxidation of the iron present in the raw material in the ferrous condition.
3. A large loss of sulphur and the almost complete oxidation of the remainder. Therefore coals high in sulphur if otherwise of the correct composition can be used without injury to the resulting product.
4. Over one-half the alkalies, potash and soda, present in the original rock were expelled in the kiln.
5. Apparently there is no loss of titanic oxide phosphoric oxide, or manganese.

Mr. Meade further finds a marked loss of material as dust during the pulverizing and burning of the raw material and clinker. If there was no such loss, and the raw materials had 5 per cent. of moisture, it would require 583 pounds of raw materials to make a barrel of cement (380 pounds) but he states that few manufacturers use less than 610 pounds, showing a loss of 27 pounds as dust, etc., per barrel of cement produced.

Fuel Supply in West Virginia.—The distribution, thickness, chemical composition, and heating value of the coals of West Virginia are discussed in detail in volume II. of the reports of this series. In selecting a coal for cement work this volume should be carefully studied.

Coal for cement burning, as has been stated, must have a high heating power, high percentage of volatile matter, low sulphur content, and a low ash percentage, not over 9 or 10 per cent. Lower grade coals may be used for the boilers and driers.

A few illustrations are selected from volume II. showing the composition of some coals in the State adapted to the burning of the cement clinker. Reference to this volume will show other coals adapted to this work.

1. The Chem. Engineer, Vol. II., No. 4, p. 221.

Geological Horizon.	Location.	Thickness. Feet.	Moisture.	Volatile matter.	Fixed carbon.
Sewickley	Sturm's Mills....	5½	1.43	38.67	51.21
Redstone	Century	6	0.67	36.21	54.38
Pittsburg	Fairmont	8½	1.62	36.70	54.44
Pittsburg	Fairmont	9	1.49	36.96	54.77
Upper Freeport	Decker's Creek...	6	1.55	30.97	59.95
Stockton	Thacker	8	0.41	36.33	58.09
Coalburg	Mammoth	4½	0.56	36.63	56.38
Winifrede	Lens creek.....	5	0.65	37.06	56.70
Cedar Grove	Monarch	3	0.69	35.92	59.24
Campbells Creek	Blacksburg	5	0.73	34.70	59.82
Brownstown	Trace Fork.....	4	0.26	36.27	56.82

Geological Horizon.	Location.	Ash.	Sulphur.	British Thermal Units.	Remarks.
Sewickley	Sturm's Mills.	8.69	4.42		
Redstone	Century	8.74	2.90	12,314	
Pittsburg	Fairmont	7.15	1.94	14,076	Enterprise mine Ave. 20 mines. Low in volatile.
Pittsburg	Fairmont	6.78	2.23	14,120	
Upper Freeport	Decker's creek	7.53	0.89	14,068	
Stockton	Thacker	5.17	0.86	14,738	
Coalburg	Mammoth	6.43	0.51	12,855	
Winifrede	Lens creek....	5.59	0.65	13,543	
Cedar Grove	Monarch	4.15	0.58	14,693	
Campbells Creek	Blacksburg ..	4.72	1.18	14,715	
Brownstown	Trace Fork...	6.65	1.72		

Natural gas fuel is available in the central and eastern portions of the State. It has been estimated that 20,000 cubic feet of gas are equivalent in heating power to one ton of good coal.

Natural gas in West Virginia is described in volumes I. and I-a of this series. It is there shown that the heat generated by natural gas combustion is due especially to the paraffines, ethane (C_2H_6) and methane (CH_4).

The proportion of paraffines and the heating power of the gas in several fields are shown in the following table from volume I-a.

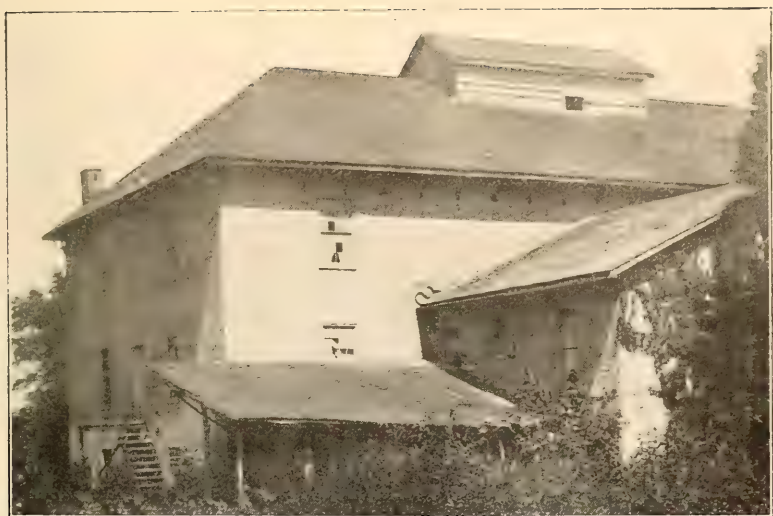


Plate XXXVI.—View of Shepherdstown Natural Cement Mill and Quarry.

	Paraffine.	Nitrogen.	B. T. U. 1 cu. ft. gas.	Paraffine.	
				Ethane.	Methane
Morgantown	95.54	3.46	1142.6	14.60	80.94
Fairmont	95.69	3.21	1136.9	14.09	81.60
Gordon sand.....	95.73	3.47	1143.6	14.88	80.85
Fifth sand.....	95.05	3.95	1131.4	14.35	80.70
Big Injun sand....	95.04	3.96	1140.9	15.09	79.95
Fifty-foot sand....	94.13	4.87	1065.3	7.65	86.48

The ethane constituent generates more heat than the methane. A cubic meter of the former generates 16,582 heat units and a cubic meter of the latter, 9,485. On burning the ethane, 92.95 per cent. of the theoretical heat is available, and on burning the methane, 90.81 per cent.

Natural gas for manufacturing purposes is sold in many parts of the State for 5 cents a 1,000 cubic feet, which would be equivalent to \$1.00 a ton for the highest grade of coal. To the cost of the coal would be added the cost of crushing and additional labor; also the interest, wear and repairs on the coal crushing plant, elevators and conveyors.

Coal Preparation.—The coal used in rotary kilns is finely crushed and blown by air blast through a pipe into the lower end of the kiln.

The coal is dried in a revolving cylindrical drier, but owing to the character of the material the heat must pass around the drier rather than through it.

The coal is then broken usually in a toothed roll cracker and finally crushed in Griffin mills or tube mills. In some plants ball and tube mills are used for grinding. The fine coal dust is carried by conveyor to storage bins near the rotary kilns and connected with them by a long pipe. Precautions in access of air to the dust and use of lights must be taken to avoid the danger of explosion.

OBSERVATIONS ON THE OPERATION OF SIXTY AND ONE HUNDRED FOOT ROTARY KILNS.¹

By E. C. Soper, of Hunt Engineering Company, Iola, Kansas.

Rotary kilns have been designed and built varying in length from 60 to 150 feet and with a diameter of from 4 to 8 feet.

1. This article forms part of a valuable paper presented by Mr. Soper before the Western Society of Engineers, Nov. 15, 1905, and kindly furnished by the author for this report.

It has been fully demonstrated that the 60-foot kilns require more fuel per barrel of cement, whether coal, gas, or oil be used as fuel, than the 100-foot kiln. The capacity has increased and the fuel consumption decreased with the increase of the diameter of the kilns within certain limits.

By repeated experiments and calculations we have determined that this proper length is from 100 to 125 feet, and a diameter from 7 to 9 feet, and that the straight kiln produces from 20 to 30 per cent. more clinker than the tapered or bottle neck kiln. In actual practice, in the same plants, working on the same materials, using the same fuel and under the same conditions, these statements have been verified.

A 60-foot by 6-foot kiln, which was the standard up to two year ago, working on the dry process and under ideal conditions, will produce on an average 175 to 200 barrels per day, and at a fuel consumption of 130 pounds of coal per barrel of clinker burned. A 100-foot kiln of 7 feet diameter, working on the same material, will produce 225 to 250 barrels per day, with 100 pounds of coal per barrel. Of course different materials vary in their burning qualities and are affected considerably by weather conditions. These and many other conditions must be taken into consideration in comparing the results obtained with rotary kilns.

Observations on the Operation of a Rotary Kiln.

The primary object of the following tests was to determine the value in point of cost of operation, fuel consumption per barrel, output per kiln, and in fact the value of the long kiln to the industry in general, and in particular, to the plant in question.

The tests were made August 31, 1905, by members of the engineering staff of the Hunt Engineering company, of Iola, Kansas, who rebuilt the plant and installed the long kilns, utilizing the old vertical kilns for clinker pits and coolers.

In order to determine the actual temperature at various points throughout the length of the kiln, which to our knowledge had never been accomplished, several holes were drilled through the kiln shell and brick lining, as shown on sketch of kiln in figure 42. A Le Chatelier electrical pyrometer was used for determining the higher temperatures, 1° Fahrenheit being equivalent to 0.0001 volts.

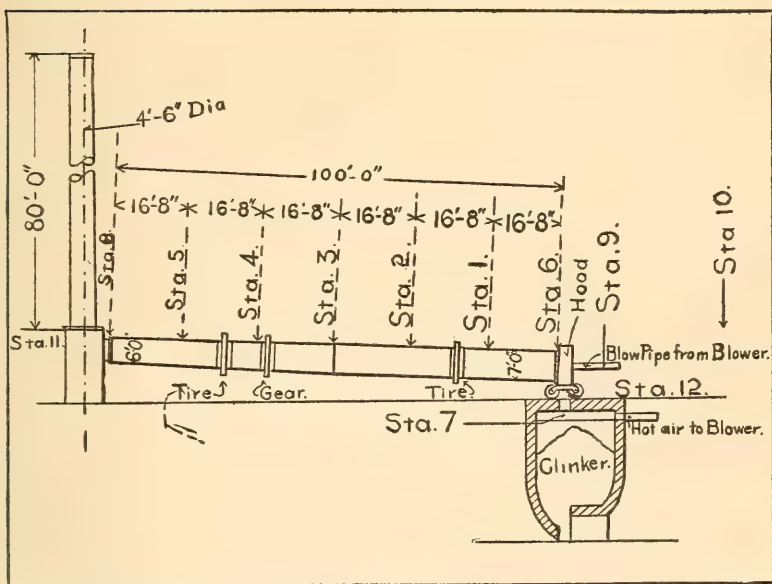


Fig. 42.—Sketch Plan of Rotary Kiln by Soper.

Readings were taken at each station every 10 seconds where the heat was intense, and every 30 seconds where there was slight danger of melting the porcelain tube. The readings were noted so long as there was a marked rise in temperature. The exact temperature at station 1 of 2496° F. is the temperature of the clinker itself and 2587° F. is the temperature of the gases.

When designing the plant the length of the kiln was calculated so as to give a stack temperature of about 400° F. operating on the materials in question. This length was determined at 100 feet, and in actual practice and operation the waste gases had a temperature of 456° F.

Conditions.

To produce one barrel of cement of 384 pounds, there is required 1,319 pounds of slurry, containing 53 per cent. or 699 pounds of water, which has to be evaporated, leaving 620 pounds of dry mixture.

With an output of 166 barrels of cement per day of 24 hours this is equal to 6.9 barrels per hour, and the time required to burn clinker for one barrel of cement is 0.145 of an hour. There is ac-

tually required 180 pounds of coal to burn one barrel of cement. The kiln is 100 feet long and 6 feet to 7 feet in diameter as shown on sketch; it is rotated at a speed of 1 revolution in two minutes, driven by a 15 H. P. motor. The stack is 4 feet 6 inches in diameter by 80 feet high.

The proximate analysis of the Iowa coal is:

Volatile matter.....	43.30	per cent.
Fixed carbon.....	30.98	" "
Ash	19.56	" "
Sulphur	6.56	" "

By calculation from this analysis the heat value of this coal is taken at 10,094 B. T. U.

Analysis of the cement material:

RAW MIXTURE.

CaCO ₃	74.46	per cent.
CaO (calculated).....	41.36	" "
Insoluble	19.50	" "
Sulphur	6.00	" "
Ignition loss.....	33.14	" "

CEMENT.

CaO	64.75	per cent.
SiO ₂	19.75	" "
Fe ₂ O ₃	6.25	" "
Al ₂ O ₃	6.50	" "
MgO	0.89	" "
SO ₃	1.90	" "

TEMPERATURES OBSERVED.

Air entering kiln from blower.....	213° F.
Air surrounding the kiln.....	102° F.
Slurry	95° F.
Average of the kiln shell.....	260° F.
Clinker, falling from the hood.....	1381° F.
Waste gases entering the stack.....	456° F.
Clinkering zone.....	2496° F.

DISTRIBUTION OF HEAT IN KILN PER BARREL OF CEMENT.

1. Evaporation of water.....	838,883	B. T. U.
2. Carbonate of lime, decomposed.....	353,200	B. T. U.
3. Sulphuric anhydride liberated.....	70,308	B. T. U.
4. Dry mixture heated to 1000° F.....	112,220	B. T. U.
5. Clinker heated to 2496° F.....	147,856	B. T. U.
6. Clinker discharged at 1391° F.....	107,835	B. T. U.
7. Radiation losses, kiln and hood.....	201,256	B. T. U.
8. Heat loss in waste gases.....	175,824	B. T. U.

Total of these items.....2,007,382 B. T. U.

But the total heat per barrel of cement supplied the kiln was 2,030,610 B. T. U., and the difference unaccounted for is 23,228 B. T. U.

If Fairmont coal from West Virginia be used with a proximate analysis of

Fixed carbon.....	53.24	per cent.
Volatile	38.10	" "
Ash	8.06	" "
Sulphur	2.60	" "

the thermic value, based on this analysis, is 12,411 B. T. U. The amount of this coal required to burn one barrel of cement is 146 pounds.

Opinion.

Assuming that certain further improvements and alterations be effected as recommended, then a further saving of 218,325 B. T. U. in the present installation can be made equivalent to 22 pounds of the "Iowa slack" coal, which will reduce the coal consumption per barrel to 158 pounds. For the sake of comparison, if Fairmont (West Virginia) coal be considered, then this reduction would be equivalent to 18 pounds, or would require 128 pounds of coal per barrel of cement burned; this is believed to be as low as it can be reduced without the installation of complicated and costly apparatus, whose utility and practicability are still to be demonstrated.

The stack gases are as low in temperature as is consistent for good draft without mechanical means. To prove the results actually obtained are as satisfactory in point of economy and cost as could be obtained through the use of the system as installed by Prof. Carpenter at Cayuga Lake (which consisted of passing the waste gases from a 60-foot kiln to the grates of boilers, and thus conserving the heat, otherwise wasted, for power purposes), the following calculations are given:

The temperature of a 60-foot kiln operating under similar conditions to those in this test can be estimated. At 50 feet (station 3) the gases in the kiln are 1581° F. and at station 4, 66 feet 8 inches from the furnace end of the kiln, they are 1291° F., so it may be assumed that at 60 feet the temperature is 1400° F.

However, in a 60-foot kiln, operating on the wet process, these gases are seldom above 1000° to 1200° F., and assuming

them at 1000° F. to conform to the foregoing calculations, the 100-foot kiln effects at the present time a saving over the 60-foot kiln of 50 pounds of coal per barrel of cement.

Then with waste gases at 1000° F. they will carry under the boiler the following heat units: In the case of the coal in question, 2160 pounds of air are required to burn one barrel of cement, and the waste gases hold 446,040 B. T. U.

Assuming a boiler efficiency of 70 per cent. then these 446,040 B. T. U. become 312,228 B. T. U. actually converted into steam for power purposes, which is equivalent to 32 pounds of coal saved per barrel of cement, by utilizing the stack gases from a 60-foot kiln operating on the "wet process."

Then the long kiln, beside being a much simpler installation and less costly, has an advantage of 18 pounds of coal per barrel of clinker burned. The long kiln will be in practically continuous operation, while in the case of the waste gas boiler installation, the one must necessarily depend, to a certain extent, upon the other in their operation.

Analysis of Samples.

If a study is made of comparison of action throughout the length of the kiln it will be noticed for the first 50 feet there is comparatively no change in the sulphur, silica, magnesia, alumina, and iron. The moisture is driven off so that at station No. 5 the material was practically bone dry. The CO_2 began to be driven off between stations 5 and 4, slowly, but starting at the middle of the kiln (station 3) it dropped rapidly for the next 33 feet. In plotting the curve of maximum temperatures of materials it is assumed that the CO_2 is driven off where the temperature of the material is 1000° F. as the temperature of the gases at this point (station 3) is 1500° F., and beginning at this point, referring to the comparison curves of analysis, the CO_2 is rapidly driven off, but the SO_3 is driven off between stations 2 and 1.

Then the probable action in the materials is this: The material is heated from its entering temperature to 212° F. where the water is converted into steam, and during this process the temperature remains constant; then the temperature rises gradually to 1000° F., where the CO_2 is given off and the temperature

again remaining constant, but rises rapidly after this action to the clinkering temperature of 2496° F. Here the temperature probably remains constant a short time, and then decreases rapidly as the cooler entering gases strike it.

The temperature of the gases is accurate within the limits of the pyrometer. A point worth mentioning is that in reconstructing this plant use was made of the old vertical kilns for clinker pits, as shown in sketch of kiln. The plant before reconstructing was not a paying proposition financially, because of the high cost of coke (from \$8.00 to \$11.00 per ton), and cost of labor due to the old methods employed. But by the installation of the long kiln, the Iowa slack coal at a cost of \$2.60 per ton and containing a high percentage of ash and sulphur, can be used. The sulphur in the raw mixtures, as will be noticed from the curve, is about 7 per cent. and is reduced to 1.78 per cent. in the clinker. The manufacturing cost per barrel has been reduced to one-half the original amount.¹

7. COOLING THE CLINKER.

The clinker from the rotary kiln has a temperature of 1200° C. (2192° F.) Before grinding it must be cooled usually in one of three ways.

1. In open or closed bins.
2. In rotary cylinders.
3. In vertical towers.

By the first method the clinker is carried by elevators and dumped into large fire proof bins or on a brick floor in large piles and left to cool by ordinary air currents. This is a slow process but requires no special apparatus and is commonly used in plants of small capacity.

In an improvement of this method the clinker drops into concrete covered cooling bins under the kilns. Cold air is driven in from below and the hot air drawn from the top is used for the air blast with the pulverized coal, so that a part of the heat in the clinker is saved.

In the second method the clinker drops from the kiln into cooling cylinders, or is carried by elevators or conveyors to these

1. End of Mr. Soper's paper.

revolving cylinders. Cold air is forced through and the heated air used with the fuel supply.

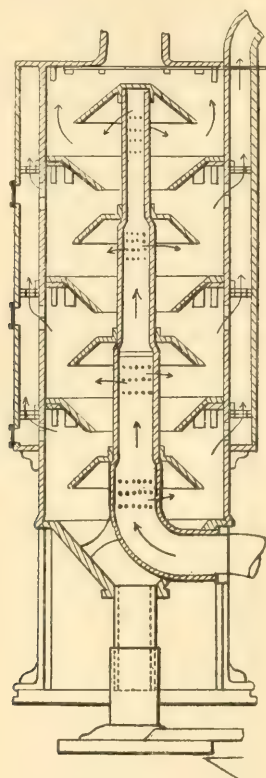


Fig. 43.

The more common method is by cooling towers. The clinker is carried by elevator and conveyor to the top of vertical towers where it falls on projecting shelves, one after another, which give the clinker a gradual fall. Cold air driven by a blast comes in below, passing up through a central flue from which it escapes through perforations beneath the shelves set on the central shaft of the tower. The cooling tower is shown in sectional plan in figure 43.

These towers are 20 to 30 feet high and 5 to 8 feet in diameter. The heated air may be drawn from the tower for use in the kilns. The capacity of such a tower is 300 to 500 barrels a day, or equal to the output of two average kilns. The cooled

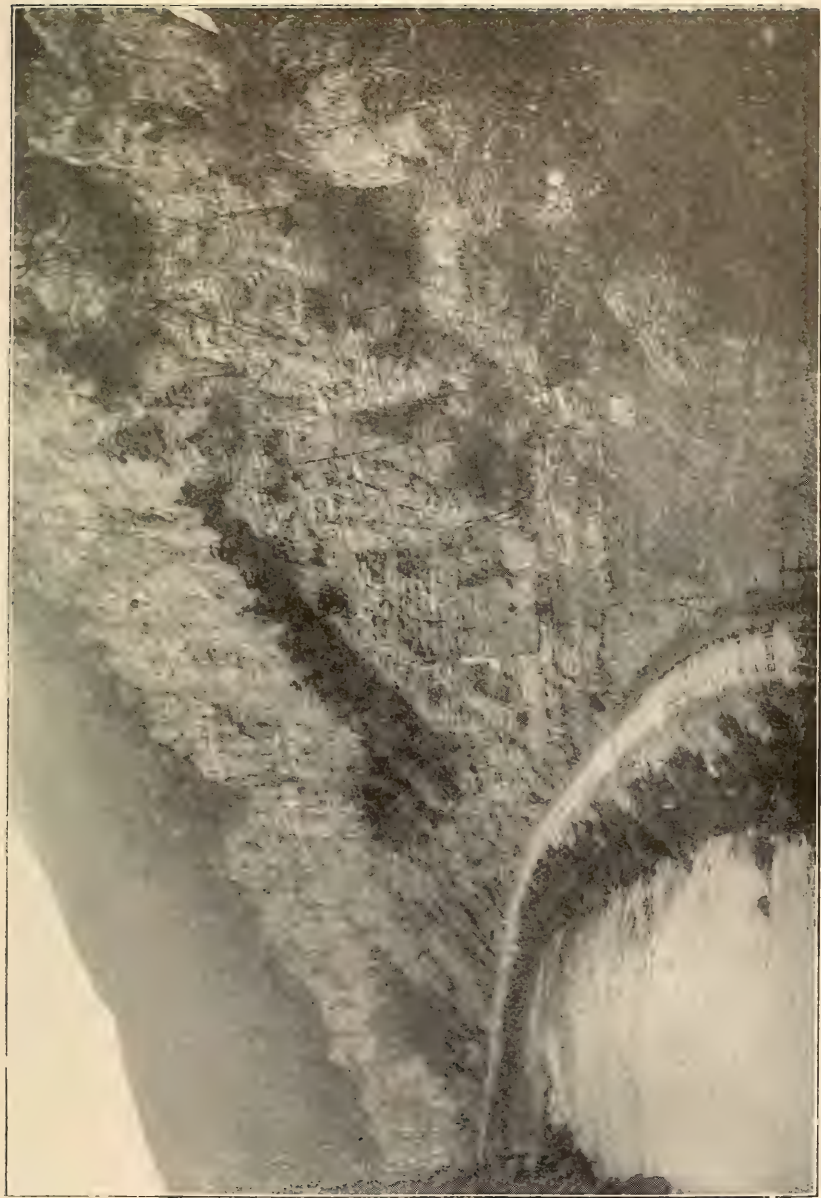


Plate XXXVII.—Lower Helderberg Limestone Along the Potomac
River and W. Va. Central Railway at Cedar Cliff.

clinker passes from the bottom by conveyors to the storage bins above the grinding machines.

According to Lewis,¹ clinker stored from 1 to 10 days will grind more readily than 6 to 8 hours after leaving the kiln. After seasoning it is said to grind 20 to 50 per cent. more rapidly in ball and tube mills than fresh clinker, thus increasing capacity, requiring less power and less wear on the mills.

8. REDUCTION OF THE CLINKER.

The clinker is ground in the same kind of mills used for the fine grinding of the raw materials. The wear on the mills is much greater. According to Lewis,² clinker grinding is the most difficult and expensive reduction required in any manufacturing process.

Cement specifications require very fine grinding. The standard fineness for Portland cement was formerly 95 per cent. passing a 50 mesh sieve or 85 per cent. passing a 100 mesh sieve. Recent American specifications require 90 to 95 per cent. to pass a 100-mesh sieve. According to Lewis the difference in output between a mill grinding 88 per cent. fine and one grinding 95 per cent. is often 100 per cent.

The capacity of the mills used and horse power required are:

	Barrels per hour.	Horse power. required.	Horse power per bbl.
Griffin mill.....	8	35	4½
Ball and tube mills.....	15	110	7½
Kent mill.....	10½	35	3½
Rolls	25	100	4

ADDITION OF GYPSUM.

Portland cement is usually quick setting, but the addition of gypsum, sulphate of lime, ($\text{CaSO}_4 + 2 \text{H}_2 \text{O}$) will act as a retarder, making the material set more slowly. This is added up to 2 per cent. to the clinker in the tube or the Griffin mills, where both are ground together. The German and English regulations and American practice limit the addition of gypsum to 2 per cent. Higher percentages are regarded as dangerous to the quality of the cement.

1. Mineral Industry, Vol. XI., p. 112.

2. Lewis loc. Cit., p. 114.

The experiments of Candlot¹ show the following influence of gypsum on the set of cement. One hundred grams of cement were used and the amounts of gypsum added as shown in the first column.

Grams of gypsum.	Initial set.		Final set.	
	Hours.	Minutes.	Hours.	Minutes.
0.0.....	0	7.....	0	22
0.5.....	0	50.....	2	40
1.0.....	2	40.....	4	50
1.5.....	2	57.....	5	17
2.0.....	3	00.....	5	20
3.0.....	3	00.....	6	40
4.0.....	3	30.....	7	00

It is thus seen that the addition of small percentages has a marked influence on the setting time of the cement. There is also a marked increase in the tensile strength of the cement, so that high tensile strengths in short time are locked upon with suspicion.

The following table by Dibdin² shows the increase in tensile strength by the addition of gypsum after 23 days:

	No. 1.	No. 2.
With no gypsum.....	618	800
0.1 per cent. gypsum.....	587	693
0.3 per cent. gypsum.....	630	750
0.5 per cent. gypsum.....	623	777
0.7 per cent. gypsum.....	590	813
1.0 per cent. gypsum.....	690	823
1.5 per cent. gypsum.....	657	890
2.0 per cent. gypsum.....	613	860

With increase above the 2 per cent. of gypsum the tensile strength increases, but in long time tests decreases. A briquette with about 5 per cent. gypsum was broken after 24 days and gave a tensile strength of 1100 pounds. In one year this broken briquette was badly checked and cracked.

PACKING OF CEMENT.³

The ground cement is carried by conveyors to bins in the storage house where it is prepared for shipment. Cement is packed in barrels, cloth sacks, or paper bags. A barrel of Port-

1. Ciments et Chaux Hydrauliques (Paris) p. 325; 1898.

2. Lime, Mortar and Cement (London) p. 128; 1868.

3. Much of data of this section furnished by Dodge Mfg. Co., Mishawaka, Indiana.

land cement weighs 400 pounds, or 380 pounds net. A barrel of western natural hydraulic cement contains 265 pounds net, and of eastern natural cement, 300 pounds net. A barrel of slag cement weighs 330 pounds net. Cloth and paper sacks usually contain $\frac{1}{4}$ barrel of Portland cement. A minimum car load of Portland cement is 75 barrels (30,000 pounds). The cloth sacks are charged in addition to the cost of the cement, the money refunded on return of the sacks in good condition.

Portland cement weighs, when loosely thrown into the measure, 70 to 90 pounds per cubic foot, or when packed 110 pounds. One barrel contains $3\frac{1}{2}$ cubic feet. Natural cement loose weighs 50 to 57 pounds per cubic foot, and when packed 80 pounds.

POWER REQUIRED AND ROPE TRANSMISSION.

According to Prof. R. C. Carpenter,¹ of Cornell University, the total power required to operate the machinery of cement plants averages very close to 1 H. P. for each barrel output per day when marl is used, and 1.5 H. P. for each barrel when rock is used. A 1200-barrel plant would require 1800 H. P.; a 2000-barrel plant would require 3000 H. P.

The power consumed in the various operations and by the various machines is given approximately in the following table in the article quoted:

Rock crushers.....	1.10	per ton.			
Rolls	1.5	per ton.			
Griffin mills on rock.....	27 to 33,	total per mill.			
Griffin mills on clinker.....	27 to 35,	" " "			
Griffin mills on coal.....	16 to 24,	" " "			
Ball mills on rock to 20 mesh.....	20 to 30,	" " "			
Tube mills, 20 mesh to dust.....	70 to 80,	" " "			
Kilns dependent on size, dry materials.....	4 to 8,	" " "			
Kilns dependent on size, wet materials.....	4 to 8,	" " "			

The elevators and conveyors would probably require 50 H. P. additional. With a central power plant, shafting is replaced to a large extent in modern cement mills by the use of rope transmission. Belts running over pulleys soon have an accumulation of dust on the pulleys which prevents the proper contact, requiring more tension, increasing friction on bearings and wear of the same. The belts are injured by action of lime and dust which

1. Concrete, Vol. II., No. 5, p. 23.

settles on them. It has been found cheaper and more efficient to transmit the power by manila ropes.

The engine drives a main line shaft which has sheave wheels on which are placed the rope cables carrying power to the different departments. The Dodge rope transmission system is used in many of the large plants of this country.

CONSTRUCTION AND COST OF A MODERN PORTLAND CEMENT PLANT.

Plate XXXII shows the construction of a modern cement plant using the dry process. The cost of a mill will vary with machinery used, size of mill, and the location. Under average conditions the cost of a plant with a total capacity of 2000 barrels a day is given approximately in the following estimate. Since the cement machinery is constantly being improved, and the prices are subject to change, it would not be possible to give any detailed statements as to cost. The following outline of machinery required for a mill of 2000 barrels daily capacity and approximate cost have been furnished by the Osborn Engineering Company.

Power House.

Building with brick or concrete walls, steel trusses, slate or tile roof.

Boilers, stack, pumps, engines, electric generators, condensers, traveling crane, etc.

Total cost, \$150,000.

Raw Material Department.

Building similar in construction to the last.

Crushers, screens, elevators, shafting.

Stone storage bins, dryers, scales, etc.

Ball and tube mills, or Kominuters or Kent mills.

Screens, elevators, motors, etc.

Total cost, \$115,000.

Kiln Department.

Building, storage bins for raw material.

Kilns, conveyors for clinker.

Line shaft, gears, clutches, motors, etc.

Total cost, \$118,000.

Clinker Grinding Department.

Building, storage bins, conveyors, elevators.

Ball and tube mills or Griffin mills, motors.

Total cost, \$92,000.

Warehouse.

Building, bins, packing machinery, hoppers, conveyors, elevators, motors, etc.

Total cost, \$38,000.

General Equipment.

Conveyors, elevators, electric lighting.

Machine shop, blacksmith shop, stockroom buildings and equipment.

Quarry equipment, drills, cars, locomotive, etc.

Preparation of site, grading, drainage, etc.

Tracks, switches, etc.

Laboratory and equipment.

Total cost, \$70,000.

Resume.

Power house.....	\$150,000
Raw material department.....	115,000
Kiln department.....	118,000
Clinker, grinding department.....	92,000
Warehouse and equipment.....	38,000
General equipment.....	70,000
	\$583,000

Such an estimate is based upon the best modern machinery and fire proof buildings throughout. A cheaper construction might reduce the cost but would be doubtful economy.

The cost of a plant of double this capacity would cost about \$1,038,000. In addition to the cost of the mill there should be a sufficient working capital.

CHAPTER XIX.

THE TESTING OF CEMENTS AND CEMENT SPECIFICATIONS.

According to Humphrey,¹ the present system of cement testing began with the experiments of Smeaton in 1756 in connection with his work on the Eddystone lighthouse. In 1858 the first systematic testing of cement was done by John Grant in London. These tests have increased in severity with a resulting improvement in quality.

The methods of testing now employed are quite similar in the various parts of the world though different requirements are found. There has been a lack of uniformity in testing in this country which has often been quite troublesome. There is no legal system of testing or of specifications adopted by the government, as is the case in Germany.

An effort has been made by the American Society of Civil Engineers to adopt a uniform method for testing cements and a special committee was appointed to make specifications for methods of manipulation, which were reported in January, 1885.

In January, 1903, a new progress report was made by a committee of this society on cement testing. Other specifications were made by the Board of U. S. Engineers, and in June 2, 1902, a committee was appointed by the American Society for Testing Materials to arrange and formulate a standard set of specifications. This committee was composed of cement manufacturers, testing experts, representatives of U. S. Army Engineering Department, railroad engineers, and architects.

Two years were devoted to the work and the resulting specifications were adopted almost unanimously by a letter ballot by the American Society of Testing Materials in November, 1904.

1. Geol. Survey of Michigan, Vol. VIII., p. 354.

These specifications will doubtless be used as standard for all work in this country and are given below.¹

AMERICAN SOCIETY FOR TESTING MATERIALS.

REPORT OF COMMITTEE ON STANDARD SPECIFICATIONS FOR CEMENT.

GENERAL OBSERVATIONS.

1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

Specific Gravity.

3. Specific gravity is useful in detecting adulteration or underburning. The results of tests of specific gravity are not necessarily conclusive as an indication of the quality of a cement, but when in combination with the results of other tests may afford valuable indications.

Fineness.

4. The sieves should be kept thoroughly dry.

Time of Setting.

5. Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden change or wide range of temperature in the room in which the tests are made, a very dry or humid atmosphere, and other irregularities vitally affect the rate of setting.

Tensile Strength.

6. Each consumer must fix the minimum requirements for tensile strength to suit his own conditions. They shall, however, be within the limits stated.

Constancy of Volume.

7. The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

8. In making the pats the greatest care should be exercised to avoid initial strains due to molding or to too rapid drying-out during the first twenty-four hours. The pats should be preserved under the most uniform conditions possible, and rapid changes of temperature should be avoided.

9. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for twenty-eight days and a retest made at the end of that period. Failure to meet the requirements at this time should be considered sufficient cause for rejection, although in the present state of

1. Published with the consent of the society through its secretary.

our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

GENERAL CONDITIONS.

1. All cement shall be inspected.
2. Cement may be inspected either at the place of manufacture or on the work.
3. In order to allow ample time for inspecting and testing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.
4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.
5. Every facility shall be provided by the contractor and a period of at least twelve days allowed for the inspection and necessary tests.
6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.
7. A bag of cement shall contain 94 pounds of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags of the above net weight.
8. Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight day tests before rejection.
9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, with all subsequent amendments thereto.
10. The acceptance or rejection shall be based on the following requirements:

NATURAL CEMENT.

11. *Definition.* This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

Specific Gravity.

12. The specific gravity of the cement thoroughly dried at 100° C., shall be not less than 2.8.

Fineness.

13. It shall leave by weight a residue of not more than 10% on the No. 100, and 30% on the No. 200 sieve.

Time of Setting.

14. It shall develop initial set in not less than ten minutes, and hard set in not less than thirty minutes, nor more than three hours.

Tensile Strength.

15. The minimum requirements for tensile strength for briquettes one inch square in cross section shall be within the following limits, and shall show no retrogression in strength within the periods specified.*

*For example the minimum requirement for the twenty-four hour neat cement test should be some specified value within the limits of 50 and 100 pounds and so on for each period stated.

<i>Age.</i>	<i>Neat Cement.</i>	<i>Strength.</i>
24 hours in moist air.....		50-100 lbs.
7 days (1 day in moist air, 6 days in water).....		100-200 lbs.
28 days (1 day in moist air, 27 days in water).....		200-300 lbs.

One Part Cement, Three Parts Standard Sand.

7 days (1 day in moist air, 6 days in water).....	25- 75 lbs.
28 days (1 day in moist air, 27 days in water).....	75-150 lbs.

Constancy of Volume.

16. Pats of neat cement about three inches in diameter, one-half inch thick at centre, tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(a) A pat is then kept in air at normal temperature.

(b) Another is kept in water maintained as near 70° F. as practicable.

17. These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, should remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

PORTLAND CEMENT.

18. *Definition.* This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent. has been made subsequent to calcination.

Specific Gravity.

19. The specific gravity of the cement, thoroughly dried at 100° C., shall be not less than 3.10.

Fineness.

20. It shall leave by weight a residue of not more than 8% on the No. 100, and not more than 25% on the No. 200 sieve.

Time of Setting.

21. It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

Tensile Strength.

22. The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified.*

<i>Age.</i>	<i>Neat Cement.</i>	<i>Strength.</i>
24 hours in moist air.....		150-200 lbs.
7 days (1 day in moist air, 6 days in water).....		450-550 lbs.
28 days (1 day in moist air, 27 days in water).....		550-650 lbs.
<i>One Part Cement, Three Parts Sand.</i>		
7 days (1 day in moist air, 6 days in water).....		150-200 lbs.
28 days (1 day in moist air, 27 days in water).....		200-300 lbs.

*For example, the minimum requirement for the twenty-four hour neat cement test should be some specified value within the limits of 150 and 200 pounds, and so on for each period stated.

Constancy of Volume.

23. Pats of neat cement about three inches in diameter, one-half inch thick at the centre, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(a) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(b) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least 28 days.

(c) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

24. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

Sulphuric Acid and Magnesia.

25. The cement shall not contain more than 1.75% of anhydrous sulphuric acid (SO_3) nor more than 4% of magnesia (MgO).

METHODS RECOMMENDED BY THE SPECIAL COMMITTEE ON UNIFORM TESTS OF CEMENT BY THE AMERICAN SOCIETY OF CIVIL ENGINEERS.¹

Sampling.

1.—*Selection of Sample.*—The sample shall be a fair average of the contents of the package; it is recommended that, where conditions permit, one barrel in every ten be sampled.

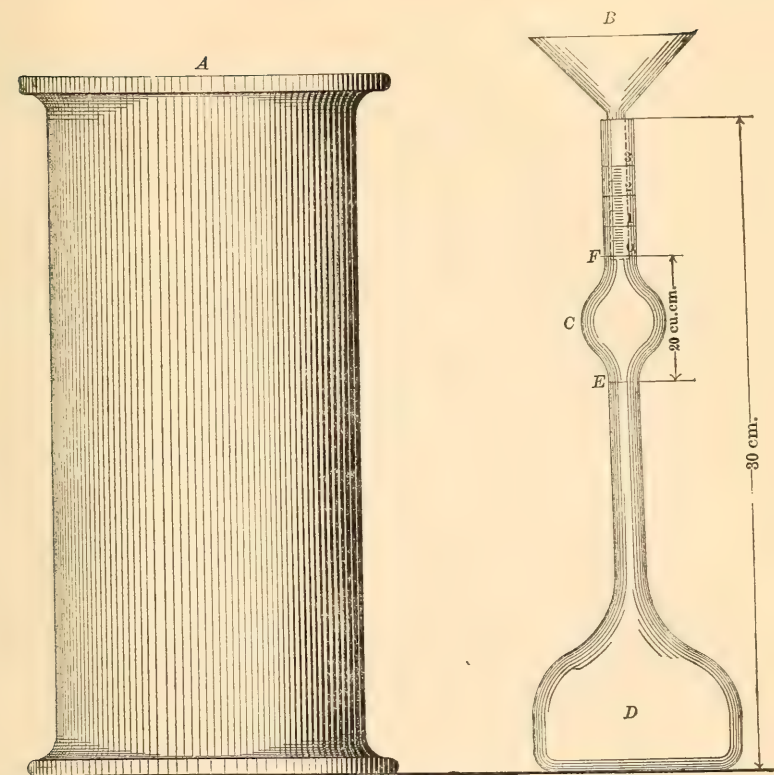
2.—All samples should be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove foreign material; this is also a very effective method for mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual samples may be mixed and the average tested; where time will permit, however, it is recommended that they be tested separately.

3.—*Method of Sampling.*—Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an augur or a sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

Chemical Analysis.

4.—*Significance.*—Chemical analysis may render valuable service in the detection of adulteration of cement with considerable amounts of inert material, such as slag or ground limestone. It is of use, also, in determining whether certain constituents, believed to be harmful when in excess of a certain percentage, as magnesia and sulphuric anhydride, are present in inadmissible proportions. While not recommending a definite limit for these impurities, the Committee would suggest that the most recent and reliable evidence appears to indicate that, for Portland cement, magnesia to the amount of 5 per cent., and sulphuric anhydride to the amount of 1.75 per cent., may be safely considered harmless.

1. Printed with consent of the society through its secretary.



LE CHATELIER'S SPECIFIC GRAVITY APPARATUS.

Fig. 44.

5.—The determination of the principal constituents of cement—silica, alumina, iron oxide and lime—is not conclusive as an indication of quality. Faulty character of cement results more frequently from imperfect preparation of the raw material or defective burning than from incorrect proportions of the constituents. Cement made from very finely-ground material, and thoroughly burned, may contain much more lime than the amount usually present and still be perfectly sound. On the other hand, cements low in lime may, on account of careless preparation of the raw material, be of dangerous character. Further, the ash of the fuel used in burning may so greatly modify the composition of the product as largely to destroy the significance of the results of analysis.

6.—*Method.*—As a method to be followed for the analysis of cement, that proposed by the Committee on Uniformity in the Analysis of Materials for the Portland Cement Industry, of the New York Section of the Society for Chemical Industry, and published in the Journal of the Society for January 15, 1902, is recommended.

Specific Gravity.

7.—*Significance.*—The specific gravity of cement is lowered by underburning, adulteration and hydration, but the adulteration must be in considerable quantity to affect the results appreciably.

8.—Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination.

9.—When properly made, this test affords a quick check for underburning or adulteration.

10.—*Apparatus and Method.*—The determination of specific gravity is most conveniently made with Le Chatelier's apparatus. This consists of a flask (D), Fig. 44, of 120 cu. cm. (7.32 cu. ins.) capacity, the neck of which is about 20 cm. (7.87 ins.) long; in the middle of this neck is a bulb (C), above and below which are two marks (F) and (E); the volume between these two marks is 20 cu. cm. (1.22 cu. ins.). The neck has a diameter of about 9 mm. (0.35 in.), and is graduated into tenths of cubic centimeters above the mark (F).

11.—Benzine (62 degrees Baume naptha), or kerosene free from water, should be used in making the determination.

12.—The specific gravity can be determined in two ways:

(1) The flask is filled with either of these liquids to the lower mark (E), and 64 grams (2.25 oz.) of powder, previously dried at 100° C. (212° F.) and cooled to the temperature of the liquid, are gradually introduced through the funnel (B) (the stem of which extends into the flask to the top of the bulb C), until the upper mark (F) is reached. The difference in weight between the cement remaining and the original quantity (64 gr.) is the weight which has displaced 20 cu. cm.

13.—(2) The whole quantity of the powder is introduced and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder.

14.—The specific gravity is then obtained from the formula:

$$\text{Specific gravity} = \frac{\text{Weight of Cement}}{\text{Displaced Volume.}}$$

15.—The flask, during the operation, is kept immersed in water in a jar (A), in order to avoid variations in the temperature of the liquid. The results should agree within 0.01.

16.—A convenient method for cleaning the apparatus is as follows: The flask is inverted over a large vessel, preferably a glass jar, and shaken vertically until the liquid starts to flow freely; it is then held still in a vertical position until empty; the remaining traces of cement can be removed in a similar manner by pouring into the flask a small quantity of clean liquid and repeating the operation.

Fineness.

17.—*Significance.*—It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

18.—The degree of final pulverization which the cement receives at the place of manufacture is ascertained by measuring the residue retained on certain sieves. Those known as the No. 100 and No. 200 sieves are recommended for this purpose.

19.—*Apparatus.*—The sieves should be circular, about 20 cm. (7.87 ins) in diameter, 6 cm. (2.36 ins.) high, and provided with a pan 5 cm. (1.97 ins.) deep, and a cover.

20.—The wire cloth should be woven from brass wire having the following diameters:

No. 100, 0.0045 in.; No. 200, 0.0024 in.

21.—This cloth should be mounted on the frames without distortion; the mesh should be regular in spacing and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.

No. 200, 188 to 200 meshes to the linear inch.

22.—Fifty grams. (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test, and dried at a temperature of 100° C. (212° F.) prior to sieving.

23.—*Method.*—The thoroughly dried and coarsely screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position and moved forward and backward, at the same time striking the side gently with the palm of the other hand at the rate of about 200 strokes per minute. The operation is continued until not more than one-tenth of 1 per cent. passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated. The work may be expedited by placing in the sieve a small quantity of large shot. The results should be reported to the nearest tenth of 1 per cent.

Normal Consistency.

24.—*Significance.*—The use of a proper percentage of water in making the pastes from which pats, tests of setting and briquettes are made, is exceedingly important, and affects vitally the results obtained.

25.—The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated the normal consistency.

26.—Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The Committee recommends the following:

27.—*Method.*—Vicat Needle Apparatus.—This consists of a frame (K), Fig. 45, bearing a movable rod (L), with the cap (A) at one end, and at the other the cylinder (B), 1 cm. (0.39 in.) in diameter, the cap, rod and cylinder weighing 300 gr. (10.58 oz.) The rod, which can be held in any desired position by a screw (F), carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame (K). This paste is held by a conical, hard-rubber ring (I) 7 cm. (2.76 ins.) in diameter at the base, 4 cm. (1.57 ins.) high resting on a glass plate (J), about 10 cm. (3.94 ins.) square.

28.—In making the determination, the same quantity of cement as will be subsequently used for each batch in making the briquettes (but not less than 500 grams) is kneaded into a paste, as described in paragraph 50, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained 6 inches apart; the ball is then pressed into the rubber ring, through the larger opening, smoothed off, and placed (on its large end) on a glass plate and the smaller end smoothed off with a trowel; the paste, confined in the ring, resting on the plate, is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

29.—The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 ins.) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

30.—The trial pastes are made with varying percentages of water until the correct consistency is obtained.

Time of Setting.

31.—*Significance.*—The object of this test is to determine the time which elapsed from the moment water is added until the paste ceases to be fluid and plastic (called the "initial set"), and also the time required for it to acquire a certain degree of hardness (called the "final" or "hard set"). The former of these is the more important, since, with the commencement of setting, the process of crystallization or

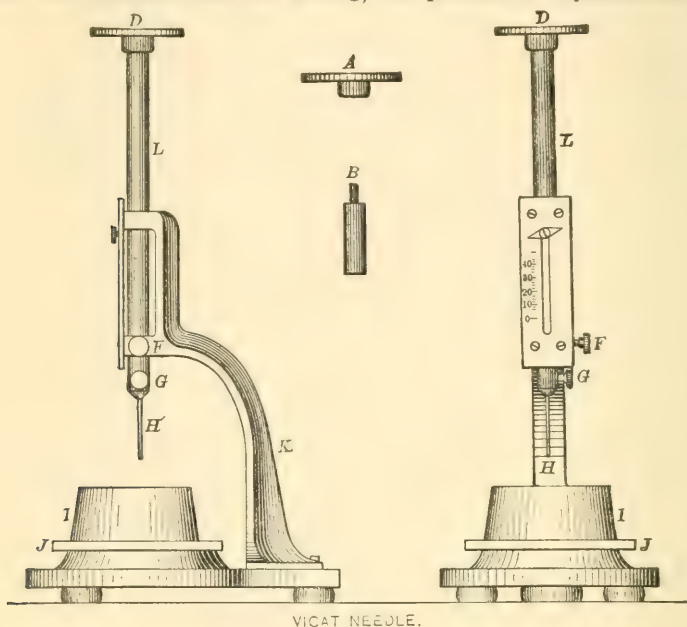


Fig. 45.

hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and moulding or incorporating the mortar into the work before the cement begins to set.

32.—It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

33.—*Method.*—For this purpose, the Vicat Needle, which has already been described in paragraph 27, should be used.

34.—In making the test, a paste of normal consistency is molded and placed under the rod (L), Fig. 45, as described in paragraph 28; this rod bearing the cap (D) at one end and the needle (H) 1 mm. (0.039 in.) in diameter, at the other, weighing 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released.

35.—The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 in.) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

36.—The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained

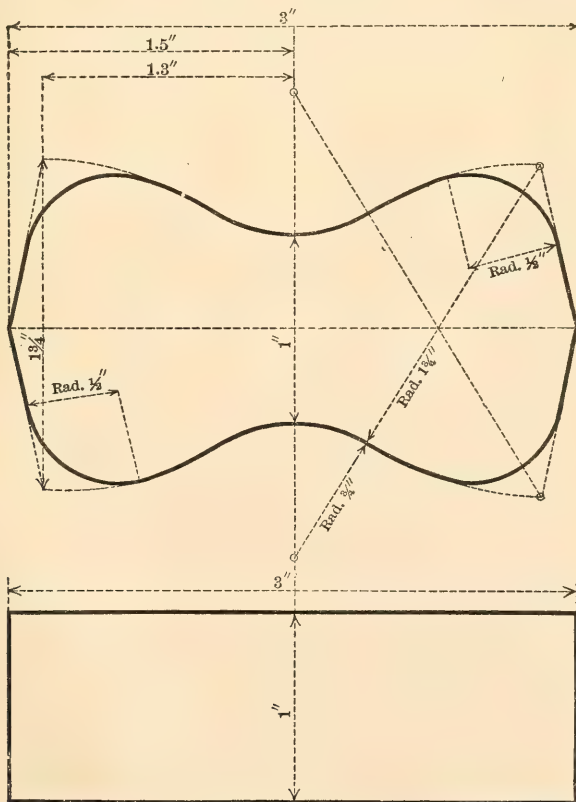
in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

37.—Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration.

38.—The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of molding the paste receives.

Standard Sand.

39.—For the present, the Committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch; the wires to have diameters of 0.0165 and 0.0112 in., respectively, *i. e.*, half the width of the opening in each case. Sand having passed the



DETAILS FOR BRIQUETTE.

Fig. 46.

No. 20 sieve shall be considered standard when not more than 1 per cent. passes a No. 30 sieve after one minute continuous sifting of the 500-gram sample.

40.—The Sandusky Portland Cement Company, of Sandusky, Ohio, has agreed to undertake the preparation of this sand and to furnish it at a price only sufficient to cover the actual cost of preparation.

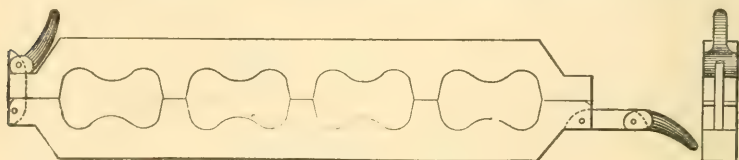
Form of Briquette.

41.—While the form of the briquette recommended by a former Committee of the Society is not wholly satisfactory, this Committee is not prepared to suggest any change, other than rounding off the corners by curves of $\frac{1}{2}$ -inch radius, Fig. 46.

Molds.

42.—The molds should be made of brass, bronze or some equally non-corrodible material, having sufficient metal in the sides to prevent spreading during molding.

43.—Gang molds, which permit molding a number of briquettes at one time, are preferred by many to single molds; since the greater quantity of mortar that can be mixed tends to produce greater uniformity in the results. The type shown in Fig. 47 is recommended.



DETAILS FOR GANG MOULD.

Fig. 47.

44.—The molds should be wiped with an oily cloth before using.

Mixing.

45.—All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material.

46.—The metric system is recommended because of the convenient relation of the gram and the cubic centimeter.

47.—The temperature of the room and the mixing water should be as near 21° C. (70° F.) as it is practicable to maintain it.

48.—The sand and cement should be thoroughly mixed dry. The mixing should be done on some non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface it should be thoroughly dampened prior to use.

49.—The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1,000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

50.—*Method.*—The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional $1\frac{1}{2}$ minutes, the process being similar to that used



Plate XXXVIII.—Greenbrier Limestone Along the Chesapeake & Ohio
Railway near Fort Spring, Greenbrier County.

in kneading dough. A sand glass affords a convenient guide for the time of kneading. During the operation of mixing, the hands should be protected by gloves, preferably of rubber.

Molding.

51.—Having worked the paste or mortar to the proper consistency, it is at once placed in the molds by hand.

52.—*Method.*—The molds should be filled at once, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mold, and, in smoothing off, the trowel should be drawn over the mold in such a manner as to exert a moderate pressure on the excess material. The mold should be turned over and the operation repeated.

53.—A check upon the uniformity of the mixing and molding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent. from the average should not be tested.

Storage of the Test Pieces.

54.—During the first 24 hours after molding, the test pieces should be kept in moist air to prevent them from drying out.

55.—A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and in consequence the test pieces are not all maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

56.—A moist closet consists of a soapstone or slate box or a metal-lined wooden box—the metal lining covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

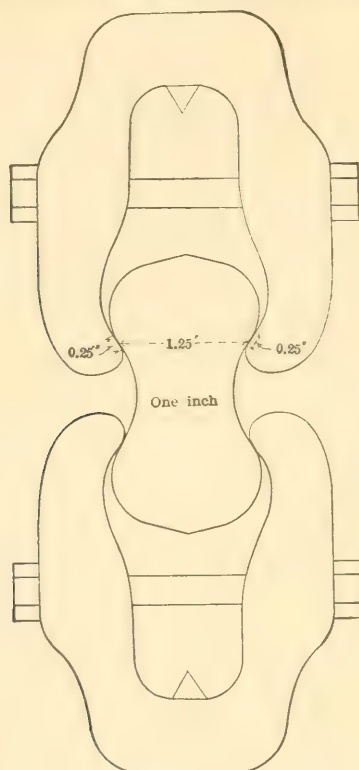
57.—After 24 hours in moist air, the test pieces for longer periods of time should be immersed in water maintained as near 21° C. (70° F.) as practicable; they may be stored in tanks or pans, which should be of non-corrodible material.

Tensile Strength.

58.—The test may be made on any standard machine. A solid metal clip, as shown in Fig. 48, is recommended. This clip is to be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be $\frac{1}{4}$ inch wide, and the distance between the center of contact on the same clip should be $1\frac{1}{4}$ inches.

59.—Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquettes in the testing machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquette be clean and free from grains of sand or dirt which would prevent a good

bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.



FORM OF CLIP.

Fig. 48.

Constancy of Volume.

60.—*Significance.*—The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

61.—*Methods.*—Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° C. (70° F.), and (2) accelerated tests, or those made in air, steam or water at a temperature of 45° C. (115° F.) and upward. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam, or preservation in air.

62.—For these tests, pats about 7½ cm. (2.95 ins.) in diameter, 1¼ cm. (0.49 in.) thick at the center, and tapering to a thin edge,

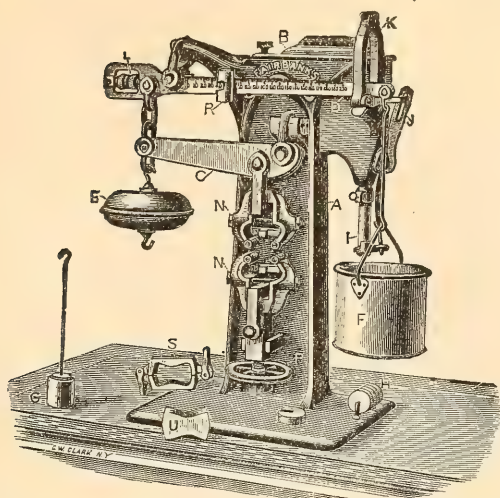


Fig. 49.—Fairbanks Cement Testing Machine.

should be made, upon a clean glass plate [about 10 cm. (3.94 ins.) square] from cement paste of normal consistency.

63.—*Normal Test*.—A pat is immersed in water maintained as near 21° C. (70° F.) as possible for 28 days, and observed at intervals. A similar pat is maintained in air at ordinary temperature and observed at intervals.

64.—*Accelerated Test*.—A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for three hours.

65.—To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion or disintegration.

6.—Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

67.—In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory because it has passed these tests.

CHAPTER XX.

CEMENT MILLS IN WEST VIRGINIA.

The present chapter, which is in reality an account of past and present development of the cement resources of the State, is a brief one. There is but one Portland cement mill and two natural cement plants, the Portland mill being the only one in operation at the present time.

BUCKHORN PORTLAND CEMENT COMPANY¹.

The Buckhorn mill is located at Manheim, Preston county, on the Cheat river, two miles below Rowlesburg. It is reached by a branch railroad from the Baltimore & Ohio. The first shipment of cement was in September, 1903; the capacity of the mill was 800 barrels a day, but has been increased to 1,200.

The buildings are of most substantial construction, being made of blue sandstone, the walls of the first story being 24 inches thick and the second story 30 inches. The roofs are covered with corrugated iron.

The mill is built on the side of the mountain below the quarry, which is 525 feet above the railroad track and 350 feet above the upper floor of the mill, as illustrated in plate XXXIII. Gravity is used to carry the rock from quarry to mill, and through it from one department of manufacture to the next, avoiding the use of elevators to a great extent. The power is transmitted from the central power house to the various parts of the mill by rope drives installed by the Dodge Manufacturing Company.

Quarry. The limestone used at the mill is the Greenbrier or Lower Carboniferous, which extends to the southward across the State. It outcrops along the side of the mountain, dip-

1. An article by the designing engineer of this plant, R. L. Humphrey, printed in *Eng. News*, Nov. 5, 1903, p. 409, has been freely used in the preparation of this description and the plates have been loaned by Mr. Humphrey.

ping to the northwest an an angle of 14° and passes under the river at a short distance below the mill.

The limestone is found in two ledges, the upper 70 feet and the lower 20 feet, separated by 100 feet of sandstone, so that the lower course is not available. The cover at the quarry consists of 12 to 15 feet of blue shales, with a thin sandstone layer. The quarry face is 30 feet high, divided into three strata, the upper 12 feet, middle 12 feet, and lower 6 feet. This quarry is illustrated in plate XXXIV. The composition of the different portions is shown in the following analyses made by the company's chemist:

	Top ledge.	Middle ledge.	Bottom ledge.
Silica	12.10	14.04	24.10
Iron and alumina.....	6.00	6.82	9.66
Lime carbonate.....	81.27	76.98	60.41
Magnesium carbonate.....	0.68	0.58	trace

In the upper stratum there is some high-grade limestone, as shown in the following analysis:

Silica	2.92
Iron and alumina.....	1.82
Lime carbonate.....	94.00
Magnesium carbonate.....	1.10

The shale and clay near the mill have the following composition, according to Humphrey:

	Shale.	Clay.
Silica	62.74	68.16
Iron and alumina.....	19.40	16.18
Lime carbonate.....	0.38	0.42
Magnesium carbonate.....	1.41	1.04

The shale and clay are not used at the present time in the cement mixture, which is made from definite proportions of the three strata. The cement mixture and the finished cement have the following composition:

	Mixture.	Sept. 1903. Cement.	Sept. 1904. Cement.
Silica	15.39	22.36	22.83
Iron and alumina.....	5.56	10.40	10.26
Lime carbonate.....	73.00	....	....
Lime oxide.....	....	62.62	62.66
Magnesium carbonate.....	....	....	....
Magnesium oxide.....	0.80	2.17	1.92
Sulphur (SO ₂).....	....	1.65	1.60

These analyses of finished cement, made one year apart, show a marked uniformity in the product. A few analyses of standard cements are given for comparison:

	St. Louis. ¹ Portland.	Alpha. ²	Saylors. ²	Sandusky. ²
Silica	22.80	22.62	22.68	23.08
Iron and alumina.....	10.90	11.42	9.06	9.06
Lime oxide.....	61.50	61.46	62.30	62.38
Magnesium oxide.....	1.25	2.92	3.41	1.21
Sulphuric acid.....	1.40	1.52	1.88	1.66

The limestone is worked in open quarry, being drilled by compressed air drills and blasted. The broken rock is loaded into five-ton steel cars, which pass down the 900-foot incline with a slope of 36°. The plane has a three-rail track extending down 340 feet to a double track separated, and 235 feet long, which permits the descending and ascending cars to pass each other. The double track then merges into a single track 340 feet long to the top of the bins at the stone house.

The two cars are attached to the ends of a steel hoisting cable, which winds around a pair of sheaves located at the top of the plane and controlled by a hand brake, the loaded descending car returning the empty.

The mixture is made at the quarry, a certain number of wheelbarrows of the different strata of rock being added to the cars. The mixture is checked in the raw material ball mill room, and if too high or too low in lime the correction is made from bins containing high and low lime rock.

Stone House. This building at the top of the mill (see plate XXXIII and figure 50) has two floors; the upper is a stone storage room to keep a surplus supply of stone for use when the quarry is shut down.

The cars from the quarry dump their load into five bins, from which the stone is fed through chutes into a champion crusher with capacity of 12 tons an hour. A gyratory crusher of large capacity is also in use.

On the lower floor are two rotary dryers, one made by Mosser, 40 feet long and 4 feet in diameter, with a fire box at one end and a brick dust chamber and stack at the other. The second dryer is a Ruggles-Coles, 24 feet long, 5 feet in diameter. The draft is maintained by an exhaust fan taking the place of the stack.

1. By John Taylor, chemist of Company.

2. Mineral Industry, Vol. VI., p. 99.

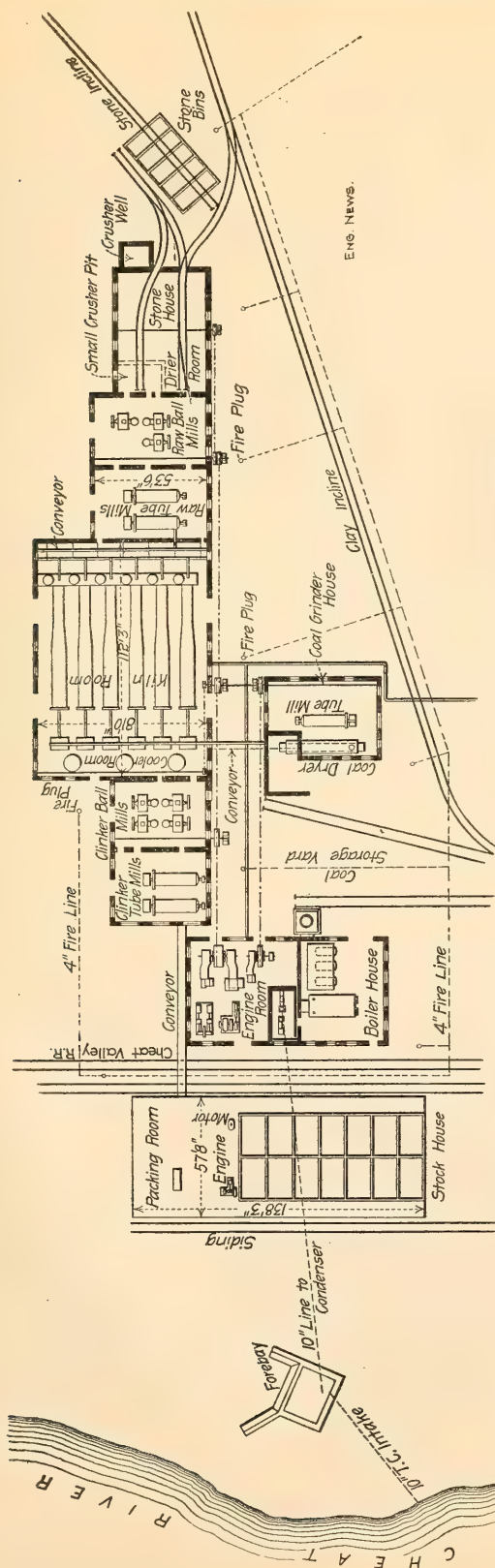


Fig. 50.—General Plan of Buildings and Plant of the Buckhorn Portland Cement Co., near Rowlesburg, W. Va.

Ball and Tube Mill Room. The stone passes from the crushers through chutes into steel hoppers, feeding three Smidth ball mills containing 2850 pounds of steel balls, where the material is crushed to pass a 12-mesh screen.

Screw conveyors carry the crushed material into hoppers, feeding three Smidth tube mills, where it is ground so that nearly 95 per cent will pass a 100-mesh screen. Three Pfeiffer and Emerick separators separate the fine and coarse material, the fine going to storage bins in the kiln room and the tailings back to the tube mills. The ball and tube mill section is just below the rock house, and next below the former section is the kiln room, as shown in figure 50 and plate XXXV.

Kiln Room. The material from the bins is fed by screw conveyors into six rotary kilns, which are 60 feet long and $6\frac{1}{2}$ feet in diameter for 30 feet, then taper for 10 feet, reducing the diameter to 5 feet for the remaining 20 feet. The inclination of the kiln toward the discharge end is $\frac{3}{4}$ inch per foot.

Each kiln is driven by a chain of gearing located about 20 feet from the discharge end. The speed varies from one revolution per minute to one in two minutes, controlled by variable speed counter shafts. The conveyor feeding the kilns is driven from the same gearing which rotates the kiln; the feed therefore varies with the speed of the kiln.

Each pair of kilns discharges through a fire brick chute into the boot of a chain open elevator, where it is sprayed with water. The elevator dumps the clinker into a Mosser cooling tower. There are three towers 32 feet high, 8 feet in diameter, having a cast iron blast pipe through the center with steel conical plates every 5 feet, extending to within 10 inches of the shell of the tower. Under the plates are holes in the blast pipe through which a flow of fresh air is maintained by a fan, the air passing out of the tower through holes in its shell.

The coolers rest on a cast iron plate supported by foundations 4 feet high in a pit about 20 feet below the kiln room floor. Under the coolers belt conveyors carry the cooled clinker to an elevator, which discharges it through an opening in the wall to the storage floor in the clinker ball mill section, located on the next lower level.

Coal Grinding. The cement clinker is formed in the kilns by the burning of a mixture of coal dust and air. The coal is run between crushing rolls, reducing it to the size of coarse sand.

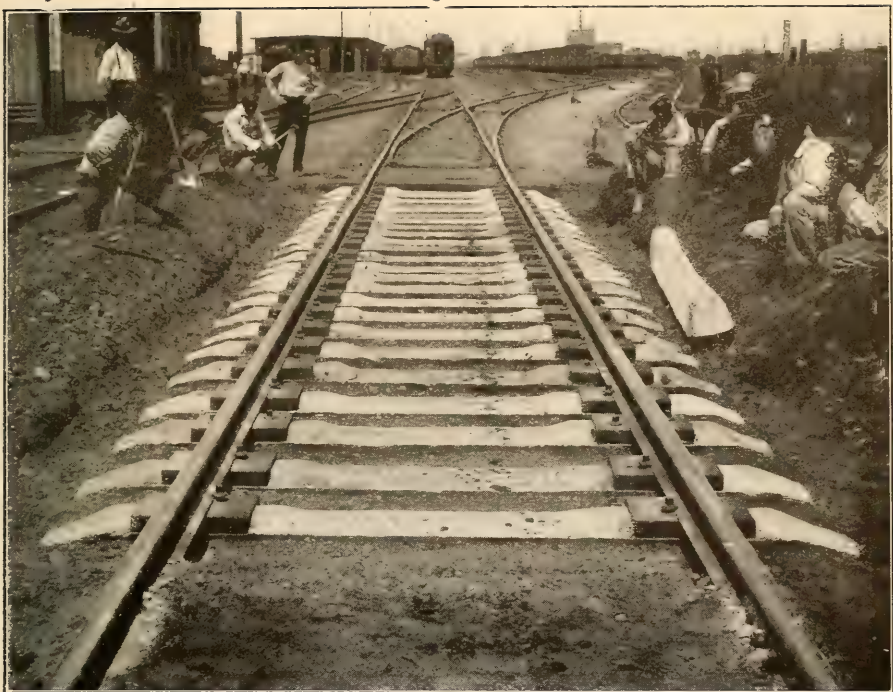


Plate XXXIX-a.—Cement Railroad Ties. (From "Cement Age.")



Plate XXXIX-b.—Kesler Hospital at Huntington, W. Va., Concrete Block Construction. (From "Cement Age.")

It is then elevated and freed from moisture in a rotary dryer and fed into a Smidth tube mill and ground so that 95 per cent will pass a 100-mesh sieve.

The pulverized coal is carried by conveyors to the fuel storage bins in the kiln room, each bin holding an eight hours' supply. The coal is drawn from the bottom of the bins by a screw conveyor and fed into the blast pipe which runs to the nozzle in front of the kiln. Low pressure air from Sturtevant blowers carries the coal through the blast pipe, and it is blown through the nozzle by compressed air.

The coal mixed with air reaches the maximum temperature about 10 feet from the inlet and fuses the materials, forming a clinker varying from the size of a pea to that of a walnut.

Clinker Ball and Tube Mill Room. From the storage floor the clinker, mixed with proper amount of gypsum, is fed through hoppers into two ball mills and one Kent mill, where it is ground to pass a 20-mesh screen. From these mills it is conveyed to the Smidth tube mills, where the reduction is completed so that 95 per cent will pass a 100-mesh sieve. Two air separators are used in connection with the clinker grinding. The ground cement is carried by conveyors over the railroad tracks into the stock house, where it is placed in bins, from which it is packed for shipment.

Storage House. This building contains the packing department and 14 bins, which are 32 feet high. The conveyor from the mill delivers the cement into an elevator, which carries it to a conveyor over the bins. There are two railroad sidings, one on each side of the stock house.

Power House. The power house is located at the bottom of the mill, and the power is transmitted by means of manila rope drives up the mountain side to the various line shafts. (See plate XXXV. and figure 50.)

The equipment includes six water-tube boilers, three 250 H. P. and three 150 H. P. There are two Buckeye engines, one 750 H. P. compound, and the other 250 H. P. simple type. The fly wheels are grooved for rope transmission. The larger engine wheel has 22 grooves, of which 18 are in use; and the smaller has 10 grooves, of which 6 are in use. A Barr 500-gallon fire pump is installed for fire protection. Water for the plant is obtained from the Cheat river, 175 feet from the power house.

A Duplex air compressor supplies air for the drills at the quarry and for the coal-burning apparatus at the kilns. The plant is lighted with incandescent and enclosed arc lights, with current generated by a 75 K. W. direct connected generator.

The Dodge system of rope transmission is used. The 18 ropes driven by the compound engine are divided into two drives of seven and eleven ropes, the former transmitting power to the shafting, driving the clinker ball and tube mills; the latter transmitting power for the operation of the raw material machinery.

The six ropes from the simple engine drive the machinery running between the kiln room and the coal department. On the inside of the kiln room a double rope drive passes to the front of the room, giving power for the fans and clinker elevators.

Office and Laboratory. A two-story frame building has the offices on the lower floor and chemical and physical laboratories above. The materials are here analyzed and tested in the different stages of the process.

Advantages and Quality of Cement. According to Mr. Richard L. Humphrey, who built the mill and was general manager until it was in full operation, "The proximity of the plant to the coal fields enables it to secure coal at very low rates. Low freight rates, cheap coal, a gravity feed from quarry to stock house, and a deposit of raw materials of exceptional quality, are advantages which permit of the production of high-grade Portland cement at a minimum cost.

"The plant has been designed with a view to future extension, and a glance at the general plan will show how readily the various buildings can be enlarged."

The following reports of testing laboratories show the quality of the Buckhorn cement:

	Booth, Garrett and Blair.	Pittsburg Testing Laboratory	Osborn Engineering Company.
Specific gravity.....	3.08	3.08	3.18
Fineness:			
No. 100 sieve.....	99.3	95.5	99.9
No. 200 sieve.....	89.0	75.5	76.9
Time of setting:			
Initial set.....	1 hr. 40 mins.	1 hr. 50 mins.	2 hrs. 35 mins.
Hard set.....	4 hrs. 15 mins.	3 hrs. 40 mins.	6 hrs. 50 mins.
Tensile strength:			
Neat 24 hours.....	422 lbs.	429 lbs.	406 lbs.
7 days.....	701 lbs.	767 lbs.	668 lbs.
28 days.....	821 lbs.	867 lbs.	899 lbs.

	Booth, Garrett and Blair.	Pittsburg Testing Laboratory.	Osborn Engineering Company.
Three parts sand:			
7 days.....	299 lbs.	262 lbs.	217 lbs.
28 days.....	456 lbs.	307 lbs.	415 lbs.
Constancy of volume:			
Steam.....	.....	.....	O. K.
Boiling water.....	.....	Satisfactory.	O. K.
Cold water.....	Sound and hard.	Satisfactory.	O. K.
Air.....	Sound and hard.	.....	O. K.
Chemical Analysis:			
Loss on ignition.....	0.90	0.76	0.96
Silica	23.72	22.56	22.72
Alumina	6.85	8.83	} 10.54
Ferric iron	3.41	3.85	
Lime oxide.....	61.54	61.75	61.76
Magnesium oxide.....	1.44	1.56	1.78
Sulphur (SO ₃).....	1.72	.....	1.75
Alkalies .....	.....	.....	0.49

NATURAL CEMENT PLANTS.

POTOMAC CEMENT COMPANY, SHEPHERDSTOWN.

The mill of this company, located one mile east of town, is one of the oldest natural cement plants in this country, being built in 1826 as a flour mill, and about 1830 changed into a cement mill. The three-story brick building, 50x100 feet, has stood the wear of the elements and the ravages of war, and to-day is a substantial structure. It has been idle since the death of its owner in 1900. A view of the building is shown in the upper part of plate XXXVI. The portion of the mill used for cement manufacture is 30x30 feet, and is equipped with crushers and three runs of buhr stones.

The rock as quarried was burned in six stone kilns, 21 feet high, 7 to 8 feet in diameter at the top, tapering at the bottom. Alternate layers of fuel and stone were added, and each kiln yielded about 50 barrels of cement a day, giving 300 barrels a day capacity, and the average production was 200 barrels (300 pounds). It was estimated that 100 tons of coal would burn 7,000 barrels of cement, and the cement cost in manufacture about 10 cents a barrel. A view of the first kiln used in burning this cement, built in 1830, is shown in the lower part of plate XXIII.

The rock burned soft and not to a clinker, so it was readily crushed. The cement was used in the locks of the Potomac

canal in 1832; in the Boundary sewer in Washington, one of the largest in the world; Army and Navy building, and other prominent structures in Washington.

The dam in the Potomac furnishes 1000 H. P., and backs the water for five miles, giving water transportation through the river to the Potomac canal and on to Washington. It is also close to the Norfolk & Western Railroad. Most of the cement made was shipped in canal boats holding 850 barrels. The name of the company was changed several years ago to Shepherdstown Cement Co.

Quarry. The cement rock forms a bold bluff along the Potomac across the road from the mill. The limestone belongs to the Cambro-Silurian, and stands nearly vertical, with a height of 125 feet. The quarry face is 57 feet across, and 15 feet has to be rejected as too pure. One of the quarry openings is illustrated in the lower part of plate XXXVI.

At one place a six-foot breast is found, which burns to a clinker and is not used. It is known by the quarrymen as the *green rock*. The exposure of vertical cliff runs for a mile and contains rock of varying composition in the different ledges, so certain portions only are used for the natural cement. The discussion of this rock for Portland cement manufacture is given in the next chapter.

The rock was analyzed in the Survey laboratory and showed the following composition. An analysis quoted by Gilmore, in 1872, is given for comparison.

	Rock Used.	Green Rock.	Gilmore Analysis.
Silica	15.89	43.67	17.84
Alumina	5.58	11.55	4.60
Ferric iron.....	0.74	0.38	1.70
Ferrous iron.....	1.00	2.91	.....
Lime carbonate.....	52.74	16.73	58.25
Magnesium carbonate.....	19.06	21.99	11.16
Alkalies	4.92	2.61	3.26
Sulphur (SO ₃).....	0.31	0.00	0.74
Phosphorous (P ₂ O ₅).....	0.12	0.19	.....
Titanium .....	.....	0.48	.....

The cement has the following composition¹:

Silica	26.65	per cent.
Alumina	12.38	" "
Ferric iron.....	2.14	" "
Lime oxide.....	33.20	" "
Magnesium oxide.....	12.56	" "

1. Mineral Industry, vol. VI., p. 96.

The cement is slow setting and has a tensile strength neat of 50 pounds in one day and 300 pounds in 28 days. The cement was tested by Gilmore¹, by molding prisms 2x2x8 inches and breaking them when set on supports four inches apart, by a pressure midway between the supports. The prisms were kept in sea water after the first 24 hours, and were 320 days old when broken. An average was taken from many trials. A few of his tests are given below:

Kind of Cement.	Pure Cement.	Vol. 1 Sand to 1 Cement.	Vol. 1 Sand to 1 Cement.
	Pounds.	Pounds.	Pounds.
Shepherdstown	747	618	450
Kingston and Rosendale.....	720	556	500
Akron, N. Y.....	764	651	603
Newark and Rosendale.....	841	560	500
Cumberland, Md.....	954	920	558
English Portland.....	1536	1260	950

CEDAR CLIFF, MINERAL COUNTY.

The Cedar Cliff Natural Cement Company built a small mill in 1891 at Cedar Cliff, a station on the West Virginia Central & Pittsburg Railroad, four miles from Cumberland. The name was later changed to the Cumberland Valley Cement Company, and the property has been in the receiver's hands for the past two years.

The mill is a frame building, two and one-half stories high, containing a 120 H. P. engine, four boilers, a crusher and four runs of buhrs. It is located on the hillside above the railroad track and not far from the Potomac river.

There are six stone kilns twenty-eight feet high and nine feet in diameter, in which the rock and fuel were placed in alternate layers. The capacity was 37 to 50 barrels of cement per kiln daily. The cement cost about 25 cents a barrel to manufacture, and it reached 115 to 140 pounds tensile strength in twenty-four hours when tested neat (without sand).

The rock was taken from three tunnels above the mill level. These tunnels have been worked under the hill for a distance of 200 feet, running a little east of south. The rock dips at a high angle and the layers vary in composition. Some of the layers can be used alone, making a quick-setting cement, but the best results were attained by a mixture of three parts of rock in the second tunnel with one from the first tunnel. Some of the layers

1. Limes, Hydraulic Cements and Mortars, p. 291, 1872.

have no cement properties, and have to be thrown aside or left in the mine. The variation in these layers, which come close together, required careful attention and skilled workmen.

The hill at Cedar Cliff is composed of folded strata of Lower Helderberg age, with the strike of the beds south of east. The dip of the rocks is quite steep, bringing the different strata to the railroad level, enabling one to follow the track across the section. The folded strata are illustrated in lower part of plate XXI. and in plate XXXVII.

The original promoters of the cement proposition recognized and numbered some forty-eight strata, and divided them into groups, named from their resemblance in composition and properties to other well-known natural cement horizons. Mr. J. C. Brady, the former manager of this property, who was very successful in turning out a high grade natural cement, has tested most of the layers and finds that many of them used alone will not make cement, and he is able to distinguish the layers and make various combinations for good cement.

The lowest group of twenty-eight feet of rock was not used at the Cedar Cliff mill, but was named the Cumberland. The next higher eleven layers, ranging from one to eight feet in thickness, or a total of $44\frac{1}{2}$ feet, were grouped as the Round Top. The next group of seventeen layers, with a total thickness of $45\frac{1}{2}$ feet, was called the Ulster or Rosendale. The highest group, of nineteen layers, with a thickness of 112 feet, was not used at the mill and so received no name.

Tunnel No. 1, near the mill, exposed the upper five layers of the Ulster, and tunnel No. 2 exposed the seven layers of the Ulster from layer No. 8 to 17. Tunnel No. 3 exposed the upper four layers of the Round Top.

Chemical Analyses. The following analyses of the Cedar Cliff natural cement rock were made by Dr. P. B. Wilson in 1891.

—————ULSTER—————		
	Stratum 14.	Stratum 17.
Silica	30.32	30.43
Alumina	4.10	5.20
Iron oxide.....	2.80	4.13
Lime oxide.....	36.77	30.86
Magnesium oxide.....	11.67	17.69
Water and carbon di-oxide.....	11.34	11.69
	100.00	100.00

The finished cement, according to the analysis of J. C. Attix, made from the rock near Ackerman, two miles above the Cedar Cliff station, contains:

Silica	27.86
Alumina	11.71
Iron oxide.....	2.72
Lime oxide.....	40.74
Magnesium oxide.....	13.95
Potash	1.30
Water	0.85
	99.13

CHAPTER XXI.

THE PORTLAND CEMENT RESOURCES OF WEST VIRGINIA.

While there is but one Portland cement mill in the State of West Virginia, that of the Buckhorn Portland Cement Company, described in the preceding chapter, the work of the Survey during the field seasons of 1904 and 1905 has brought to light a number of very promising locations for this work, which will be described in this chapter.

The conditions necessary for desirable cement mill locations are given below, and the locations described in this chapter possess all of these advantages.

1. Materials (limestone or marl, clay or shale) of the correct composition must be present in sufficient quantity to supply a mill for a long period of time. A thousand barrel plant will use about an acre of limestone, thirty feet thick, in one year.

2. The amount of rock or soil cover should be comparatively small, the smaller the better, as a large amount of cover through the cost of its removal will make the cost of quarrying the materials too high.

3. There should be a good water supply near at hand for steam purposes, use in the mill and for fire protection.

4. Cheap fuel, either gas or coal, is necessary. It requires about 200 pounds of coal or 2,000 cubic feet of gas to make a barrel of cement, including the fuel used for power, drying and burning.

5. There must be good transportation facilities by water, rail, or both, and the distance to large markets should be as short as possible in order to lower the freight rates. A barrel of cement weighs 400 pounds, so that an increase in freight rate of 50 cents a ton would increase the cost 10 cents a barrel.

Companies prefer to have two competing lines of transportation available, but this condition is not essential.

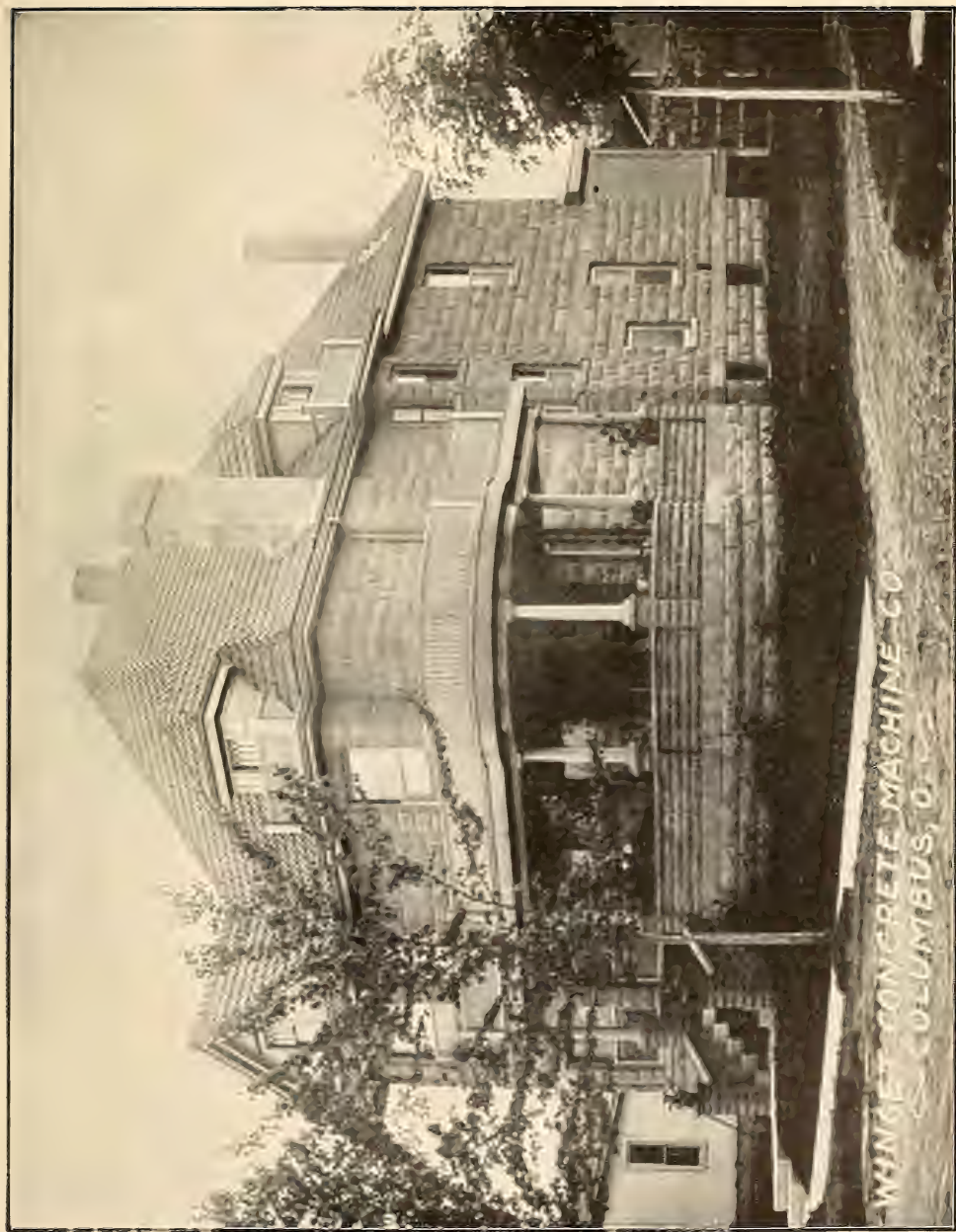


Plate XL.—Residence Built of Winget Concrete Blocks,

6. A good building site is necessary for the various buildings, and it should be large enough for the first buildings and for future additions as the industry grows. There should also be room for the railroad sidings. The building site should be near enough to the quarries to avoid long haulage, and at the same time far enough away to avoid any danger from blasting.

7. If the cement materials are found above the site of the mill there will be an advantage in location, as gravity can be used in their delivery to the mill.

8. Nearness to a town or city will often make it easier to secure laborers.

9. The price of the land should not be placed at an exorbitant figure or it will prevent the location of mills where all the conditions are favorable.

VALUABLE PORTLAND CEMENT LOCATIONS.

MARTINSBURG, BERKELEY COUNTY.

Martinsburg, the county seat of Berkeley county, located in what is termed the eastern Panhandle of West Virginia, is a city of 12,000 people. It has a number of manufacturing plants, is a division point on the main line of the Baltimore & Ohio Railroad, and is also on the Cumberland Valley Railroad. The distance to Washington is 74 miles, to Baltimore 100 miles, and to Philadelphia 195 miles. The freight rate on cement from this point to Baltimore or Washington would be about 22 cents a barrel. The distance west to Pittsburg would be 228 miles.

Geology. The rocks of the county are limestone and shales of Cambrian and Silurian age, forming belts of varying width trending northeast-southwest, and extending to a depth estimated at 200 to 300 feet. Quarries worked to a depth of nearly 100 feet show no signs of exhaustion of the rock. The county has for many years been famous as a producer of lime and limestone flux. Train loads of these materials are shipped daily to the east and west, and the lime quarries have made their owners wealthy.

RAW MATERIALS.

Limestone. The limestone of Berkeley county has been named the Shenandoah limestone, and belongs to the Cambro-

Silurian geological period. This limestone covers a large area in the county, but varies greatly in composition in different parts of the area. It appears to run in belts, which are quite uniform in composition within the belt. Some of these belts are dolomites of almost theoretical purity, as shown by analysis. Other belts, while not true dolomites, are high in magnesia and probably would not be suited to cement manufacture. The dolomites used in open hearth steel reduction, lining of converters and the dolomitic limestone valuable for ballast, or for concrete, could be worked by a cement company as separate industries if it seemed advisable to the company. The market for these products is reported good.

Near Martinsburg there is a belt of limestone trending 25 degrees east of north, and traced for a distance of ten miles with a width varying from 25 to over 300 feet, which will average in composition over 95 per cent of lime carbonate. A large part of it will run 98 per cent, and in places it will analyze 99 per cent pure. The limestone near this belt will run about 90 per cent.

The limestone comes to the surface of the ground in many places. In other portions of the area there is a surface cover of a few feet of red clay, resulting from the weathering of the limestone. In color the rock is nearly white.

Chemical Analyses. The following analyses were made on the limestones near Martinsburg by the Survey:

	No. 42.	No. 45	No. 54	No. 49
Lime carbonate.....	96.82	95.44	89.91	98.21
Magnesium carbonate.....	1.29	2.51	3.18	0.86
Alumina and iron oxides.....	0.62	0.69	2.00	0.75
Silica	0.69	0.60	3.81	0.02
Sulphur	0.07	0.12	0.25	0.09
Phosphorus	0.02	0.05	0.12	0.007
	99.51	99.41	99.27	99.937

No. 42 is from the Alex. Clohan farm, west of town.

No. 45 is from the Baker Brothers' quarry, east of town, where the rock is quarried for railroad ballast.

No. 54 is from Baker Brothers' quarry at Kearneysville, eight miles east of Martinsburg.

No. 49 is from Keller Brothers' lime quarry at Engles, fifteen miles east of Martinsburg.

The limestones from which these analyses were made were taken from locations widely separate and give an idea of the composition over a large area.

Analyses will now be given of specimens selected from a few hundred acre tracts near Martinsburg illustrating the difference in composition in belts trending northeast-southwest. On the Rutherford farm, east of town, the high-grade rock is found in two belts, which branch from a point beyond the farm house and run southeast and southwest, forming a V, with the width of the lines of the V several hundred feet wide. In the following set of analyses the numbers refer to the place of the limestone samples, as follows:

No. 153 is of the limestone on the southeast line of the V, and about 200 yards from the angle of the lines.

No. 155 is of sample from the other branch of V, and probably 800 yards from the angle, and on the Rauch farm, adjoining the Rutherford farm.

No. 154 is from limestone on Clohan farm, on the same branch of the V as sample 155, and a few hundred yards farther south.

No. 152 is from limestone regarded as lower grade taken from the area between the lines of the V.

The Baker quarry limestone, the analysis of which is given above No. 45, is just west of the V.

	No. 153.	No. 155.	No. 154.	No. 152.
Lime carbonate.....	98.25	87.73	95.12	78.90
Magnesium carbonate.....	1.41	9.78	2.87	11.66
Silica	0.73	2.03	1.65	7.01
Iron and alumina.....	0.41	1.23	0.43	2.49

Another area may be taken to illustrate the belts of limestone of different chemical composition with a trend northeast-southwest on the Nicklas, Paulding, Van Metre farms, east of Martinsburg. On the Nicklas farm is located a small fish pond and the rocks are well exposed near this place. In a distance of a little over one-fourth mile east and west there is a belt of high-grade rock (A and 149), then a lower grade limestone in a narrow belt (B and C, 160), and a dolomite belt (167, 168), which becomes lower in magnesia to the south about a half mile (157), near a small belt of shale included in the limestone area; a high-grade belt at the pond (150), which is at least 400 feet in width (D). The belt of high-grade rock continues north on the Paulding tract, and traced to the east a distance of 300 feet is still good rock (164), becoming dark in color, almost black, and more impure near the shale or slate contact on the east (148). The high-grade rocks are light colored and very close grained, breaking with conchoidal fracture, giving smooth surfaces. The dolomite is brownish in color and not so close grained as the last.

The rocks with lower lime percentage are blue to black. These differences in texture and color soon enable one to separate the belts by appearance of the rock. The chemical composition of the rocks in these belts is given as follows, and the letters and numbers are explained above. The analyses marked by letters were made for a local company by L. S. Kershner, of Dunbar, Pa., those designated by numbers were made in the Survey laboratory.

	A.	No. 149.	B.	C.	No. 160.	No. 150
Lime carbonate.	99.07	98.98	93.85	92.03	92.08	99.36
Magnesium carbonate	0.31	0.43	3.33	5.24	3.48	0.23
Silica	0.25	0.58	1.58	1.86	3.83	0.79
Alumina.....	0.37	0.13				
Iron oxide.....		0.75	1.24	0.93	1.14	0.31
	D.	No. 167.	No. 168.	No. 157.	No. 164.	No. 148
Lime carbonate.....	98.42	59.36	58.47	82.85	94.93	90.73
Magnesium carbonate	0.57	36.08	37.50	15.38	3.91	2.33
Silica	0.74	4.43	3.85	1.39	1.39	5.77
Alumina	0.27					1.24
Iron oxide.....		0.91	0.92	0.57	0.74	0.61

Eight miles south of Martinsburg, near Bunker Hill, at the Kline lime quarry, the same arrangement of the rock in belts of different chemical composition is found.

No. 145 is the limestone in the Kline quarry.

No. 161 is nearly 200 feet west of the quarry and near the edge of the belt of high-grade rock.

No. 156 is 50 to 75 feet farther west, in a different belt of rock, as shown by the analysis as well as by a change in color of the rock.

No. 159 is one-fourth mile south and on a belt different from the last two.

No. 146 is a dark-colored rock near the town of Bunker Hill, and is claimed to have been burned into natural cement.

	No. 145.	No. 161.	No. 156.	No. 159.	No. 146.
Lime carbonate.....	97.17	97.05	50.58	87.90	67.88
Magnesium carbonate..	1.26	2.63	33.77	8.08	9.09
Silica	0.60	0.59	9.80	3.41	15.84
Alumina	0.09		3.84		4.79
Iron oxide.....	0.37	0.47		1.38	
			0.20		1.26

Shale and Clay. The limestone as described in the preceding sections would furnish the lime for Portland cement manufacture. There would be required in addition a source of silica and alumina, which is found in this area in the shales or in the clays.

The shales known as the Martinsburg shales of Silurian age form belts of varying width, bordering the limestone, and average several hundred feet. Both limestone and shale dip at steep angles, being nearly vertical over a large portion of the area near Martinsburg. The very high-grade limestone belts appear to follow the shale contact, or are found as lenses in the shale.

This shale in the last few years has attracted considerable attention as roofing slate, and some half dozen companies have been organized to develop it. The most extensive development has been made by the Shenandoah Slate Company, of Washington, D. C., which has opened a quarry sixty-five feet in depth, and has a small mill equipped with sawing, grinding and polishing machinery. The slate has been used in interior construction work and is claimed to have given good satisfaction. Large slabs can be taken out and take a very good polish. As roofing slate it has not yet proved successful, though the promoters claim that with depth the slate will prove to be a good roofing material. Our laboratory tests on the specimens taken from the present openings show a tendency in the slate to disintegrate and crack when exposed to acid atmosphere, and blocks left out in frost and weather crack.

The Martinsburg slate as a roofing slate proposition is doubtful, but it is adapted to the manufacture of Portland cement, in connection with the limestone. The following Survey analyses have been made of these shales, or slates as they are locally called:

	No. 43.	No. 58.	No. 59.	No. 79.	No. 90.	No. 189.
Silica	56.67	56.29	53.30	57.75	70.41	60.23
Alumina	19.52	17.85	18.16	20.17	10.20	18.98
Ferrie iron.....	3.06	2.41	1.95	7.00	7.11	6.07
Ferrous iron.....	4.00	4.58	4.58	0.23	0.45	0.39
Lime oxide.....	2.23	2.88	4.89	0.22	0.50	0.56
Magnesium oxide..	1.94	2.63	2.65	1.22	0.58	0.86
Sodium	0.96	1.02	0.82	0.62	0.37	0.53
Potassium	3.08	3.56	3.70	2.59	1.73	3.06
Water	0.36	0.31	0.68	2.75	1.82	2.37
Titanium	0.86	0.78	0.72	0.87	1.20	0.89
Phosphorus	0.45	trace	0.24	0.09	0.26	0.12
Sulphur	0.99	1.28	0.77	none	none	....
Loss on ignition...	5.56	6.84	7.36	5.94	5.05	6.28
	99.68	100.43	99.82	99.55	99.68	100.34

No. 43 is the shale on the Mose Tabler farm, four miles northeast of Martinsburg.

No. 58 is the shale on L. Tabler farm, two miles from the last.

No. 59 is the shale from deep quarry of Shenandoah Slate Co.

No. 79 is the weathered surface shale used at the Buxton brick yard, near Martinsburg.

No. 90 is the river clay sampled on the Walter Snyder farm.

No. 189 is the river valley clay on Wellschance farm, north of Martinsburg.

A study of these analyses according to the rules and conditions outlined in chapter XVII of this report will show that the clay (No. 90) is too high in silica in proportion to the alumina, as the ratio of silica to alumina is nearly 7 to 1, when it should be between 3 and 4 to 1. This is a very sandy clay. Other valley or river clays near Martinsburg appear to be less sandy and may possibly prove valuable for cement.

The weathered shale at Buxton yard is low in silica in proportion to the alumina having a ratio of 2.3 to 1. To use this shale with the limestone would probably require the addition of sand to increase the amount of silica.

The ration of silica to alumina in No. 43 is 2.9 to 1; in No. 58 it is 3.1 to 1; in No. 59 it is 2.9 to 1. These shales could be used with the limestone for cement. The mixture of shale No. 43 and limestone No. 42 was calculated in chapter XVII and the result gave 100 parts of shale to 339 parts of limestone for the proper mixture.

Advantages of Location.

The supply of materials described in the preceding section is practically unlimited and would be sufficient for a number of plants for centuries. If the limestone is only 120 feet in thickness, which is a conservative estimate, one acre would last a 2,000-barrel plant two years, or 100 acres would last 200 years. It would, however, be more economical to work a large area with less depth of quarry and the supply would still be almost unlimited. A further advantage is the proximity of the two necessary materials, shale and limestone, as they occur side by side and it is possible to find fields in which half the area is limestone and the other half shale.

Water supply is constant and abundant. The Opequon creek is a stream of good size and flows over part of its course along the contact of the shale and limestone. The Potomac river has high limestone bluffs in part of this area and is only eight to ten miles distant from a large portion of the Martinsburg area. On

this river has been built an electric power plant using the water power of the river. This plant now supplies light and power to the town of Martinsburg. An increase in its capacity would enable the plant to supply the cement mills with cheap light and power.

There are a number of good tracts of land on the market which are on the main line of the Baltimore & Ohio railroad, so that the mills would require only short switches, and most of the territory could be reached by a mile or two or siding.

The topography is rolling and adapted for building sites of any size. The entire cost of manufacture of Portland cement should not exceed 65 cents a barrel, which would enable a company to place cement in Baltimore or Washington at 85 cents a barrel, which at present prices, would yield a good interest on the investment.

The best grade of cement coal used throughout the United States east of the Mississippi river is the Pittsburg coal from the Fairmont and Monongahela river region. This coal can be shipped for the rotary kilns at Martinsburg for about \$1.75. Cheaper fuel could be secured from the mines near Cumberland, 75 miles distant, for power or boiler use.

In addition to the cement manufacture, a comparatively small additional expense would add crushing capacity for ballast rock and for the crushing of the high grade rock for use as flux in the steel works of Pittsburg and Baltimore. The screenings would be available for concrete. The high grade rock and the dolomite could be burned into lime which would reach a wide market, as lime is now shipped into this State from Pennsylvania, Maryland and Ohio, though lime is also shipped from Martinsburg to New York, Baltimore, and Pittsburg. It is estimated that the cost per bushel of burning the lime would be between 8 and 10 cents, and it should bring 15 cents per bushel F. O. B.

Locations for Cement Mills.

In a State report of this kind it would not be in place to recommend tracts of land that are especially suitable for the location of mills, by the name of the owners, as the object of the report is to advertise the resources of the State and call attention to desirable sections for the location of industries. The reports cannot be used to advertise certain farms or syndicate lands.

There are a number of tracts near Martinsburg which possess the advantages for cement mill locations as described in the preceding paragraphs, and companies wishing to secure desirable locations can soon find them by visiting the area described. These tracts are for the most part held at reasonable prices and the people of this section are friendly to new enterprises and will encourage their location.

SHEPHERDSTOWN, JEFFERSON COUNTY.

Shepherdstown is the oldest town in West Virginia, and is situated at the northern edge of Jefferson county on the Potomac river. One of the oldest natural cement mills in the country is located here, started in 1830 and operated from that time to 1900 except during the years of the Civil War.

Cement Materials.—The Shenandoah limestone forms a vertical bluff along the river for over a mile near the cement mill, with a height of 125 feet. (See plate XXXVI.) The strata stand almost on edge, and vary in short distances in texture and composition. In the work of the old mill it was found that certain strata were suitable for natural cement, and others were too pure and were left behind. A large amount of material has been quarried, but there is plenty of rock left which is suitable for natural cement.

The Shenandoah limestone is found over large areas around Shepherdstown and has been quarried at a few places for local use. The composition of the natural cement rock near the mill is shown by the following Survey analyses:

	No. 51.	No. 53.	No. 106.	No. 107.	No. 111.	No. 112.
Lime carbonate.....	16.73	52.74	47.42	70.43	23.51	68.79
Magnesium carbonate...	21.99	19.06	29.73	11.39	26.42	17.04
Silica	43.67	15.89	13.44	11.04	34.82	10.32
Alumina	11.55	5.58	5.68	2.20	11.92	2.72
Iron	3.29	1.74	2.06	1.65	3.50	1.63
Alkalies	2.61	4.92	.....	.....	.....	.....
Titanium	0.48	.....	0.16	0.19	0.43	0.09
Phosphorus	0.19	0.12	.....	.....	.....	.....
	100.51	100.05	98.54	96.90	100.60	100.59

All of these rocks are seen to be high in silica and alumina, also high in magnesium carbonate. None of them would be suitable for Portland cement.



Plate XLI-a.—Turner System of Reinforced Concrete Floor.
(From "Concrete.")



Plate XLI-b.—Reinforced Concrete Dam at Wilton, New Hampshire.
(From "Concrete.")

No. 51 is from a ledge near the old mill, which is said to burn into a good natural cement, but forms a clinker which must be ground.

No. 53 is about ten feet from No. 51, but slakes on burning, and was used in the later work of the plant.

No. 106 is from a rock used for natural cement.

No. 107 is from a nearly vertical wall, and a large portion of it has been removed for cement. Ten or twelve feet of the rock still stands and towers up 100 feet or more in height.

No. 111 is the cement rock just east of sample 51 and was used at the mill.

No. 112 is from one of the older quarries and the one nearest town. The quarry has been abandoned for many years, but the rock was regarded as exceptionally good for natural cement.

The natural cement rock has been worked back into the hill by open cuts, leaving the clinkering natural cement rock and the stone regarded as useless for natural cement projecting between the small quarries. While the natural cement rock is high in magnesia, other layers of the limestone contain low percentages of this element as shown by the following analyses, except No. 144:

	No. 108.	No. 109.	No. 110	No. 114.	No. 113.	No. 50.	No. 144.
Lime car- bonate ..	90.18	81.90	85.42	94.82	83.61	80.69	48.47
Magnesium carbonate	3.27	9.59	10.14	4.45	6.19	7.48	28.95
Silica	4.84	6.18	3.42	0.70	6.24	5.21	13.18
Alumina ..	0.91	1.57	0.59	0.08	1.17	3.90	5.88
Iron	1.03	1.03	1.03	0.82	1.23		2.45
Titanium ..	0.06	0.12	0.06	trace	0.04	0.12	0.23
	100.29	100.39	100.66	100.87	98.48	97.40	99.16

No. 108 is a blue limestone which is near the natural cement rock No. 106.

No. 109 is one-eighth of a mile west of last, where the rock is greatly folded. There is a large body of this rock, but the percentage of magnesia is high.

No. 110 was taken 300 feet west of the last and probably represents the same stratum.

No. 114 is from a high grade stratum, two feet thick at outcrop, but there are a number of layers in the section that appear to be similar to this one.

No. 113 is the rock near town and extends over a large area around the town.

No. 50 is two miles west of the last and near the western edge of town and shows a similar composition. The only trouble with these rocks is the high percentage of magnesia.

No. 144 is one-fourth mile east of No. 113 and is west of the natural cement quarries and is a dolomite.

A deep ravine cuts through the limestone just west of the first quarry where sample 112 was taken, and this ravine has always been looked upon as separating the natural cement beds from the

main mass of limestone to the west. The few analyses made of this material appear to confirm this observation.

On account of the high percentage of magnesia in the impure limestones, it would be practically impossible to mix the limestones for Portland cement. The purer strata of limestone might be selected and mixed with clay or shale to form the proper mixtures. Before the possibilities of the industry could be fully determined borings should be made back from the river bluff to determine the extent of the pure strata.

The clay over the limestone in this area has the proper silica-alumina ratio, but is rather high in ferric oxide, reaching seven and eight per cent., giving it a bright red color. River clays are not present in any quantity in this section, but they are found a few miles distant.

The Martinsburg shales could be brought to this section by water, the distance by the canal being about twelve miles, or the shale known as the Harpers shale is found on the Maryland side about four miles away and could be reached by canal.

Advantages of Location.

The dam in the Potomac, which at the present time is out of repair, furnished water power for the old cement mill, and was estimated to give 1000 H. P. The water was backed for five miles giving connection with the Chesapeake & Ohio canal, and through this waterway the cement was shipped to Washington at a cost of 8 cents a barrel, while the rail transportation was 16 cents. The area is also reached by the Norfolk & Western railroad.

The rock along the river forms a vertical cliff with a height of 125 feet with practically no cover, so that it could be worked in open quarry. The Fairmont coal for the kilns could be shipped part of the way by water and probably reduce the cost. Good building sites could be secured within a mile of the town.

CHARLES TOWN AND MILLVILLE, JEFFERSON COUNTY.

The rock formation at Charles Town is the Shenandoah limestone which has been quarried on a small scale for building stone and road material. Six miles east on the Baltimore & Ohio at

Millville are the large limestone quarries of the Baker Brothers and Harpers Ferry Lime Company.

Some of the limestone near Charles Town appears to be high in magnesia, and the Baker quarry at Millville is a dolomite, which is also found across the Shenandoah river at the quarry of the Harpers Ferry Lime Company, but this company has also opened quarries in pure limestone. The composition of these limestones is given by the following analyses:

	No. 47.	A.	B.	No. 50.	No. 169.
Lime carbonate.....	54.72	53.67	97.50	80.69	55.00
Magnesium carbonate.....	39.54	44.39	....	7.48	45.00
Silica	0.05	0.66	0.53	5.21	0.40
Iron and alumina.....	0.89	0.47	0.70	3.90	0.41
Alkalies	0.15	....	....	....	....
Phosphorus	0.01	....	....	0.12	....
	<u>95.36</u>	<u>99.19</u>	<u>98.73</u>	<u>97.40</u>	<u>100.81</u>

No. 47 is the dolomite at Baker quarry, Millville.

A is the dolomite at Harpers Ferry Limestone Company quarry, and the analyses A and B were made by the Carbon Steel Company chemist.

B is the pure rock from the quarry of Harpers Ferry Limestone Company.

No. 50 is the limestone near Charles Town.

No. 169 is the dolomite in the old quarry of Baker Bros.

The following analyses of the Millville dolomites have been made by the Survey and of the limestones on the Wetzel farm and near Millville:

No. 170 is a dolomite from the quarry of the Harpers Ferry Lime Company and nearly opposite the Baker quarry (169) but across the Shenandoah river.

171 is one-fourth mile west of last.

No. 172 is a dolomite one and one-half miles west on the Wetzel farm on the hill above the marl deposit.

No. 158 is from near the old lime kiln on property of Harpers Ferry Lime Company.

No. 163 is the rock to the west of the Wetzel farm house.

No. 166 is a shaly limestone about one-fourth mile from the last on the hill slope to the run.

	No. 170.	No. 171.	No. 172.	No. 158.	No. 163.	No. 166.
Lime carbonate.....	55.00	54.00	55.00	92.96	88.04	93.38
Magnesium carbonate..	45.00	46.00	45.00	4.62	9.47	2.73
Silica	0.30	0.53	0.29	1.70	2.53	3.64
Alumina and iron.....	0.57	0.47	0.59	1.29	0.71	0.85

On the Wetzel farm near Millville is a deposit of marl fifteen feet thick where the creek cuts through it and extending over a large acreage. The marl is granular and light gray color. It is

reported from other parts of this county. Below is given an analysis of this marl and of one of the marls used in the Michigan cement work:

	No. 115.	Michigan. ¹
Lime carbonate.....	92.26	95.13
Magnesium carbonate.....	1.54	2.04
Silica	1.80	1.22
Alumina	1.23 }	0.61
Iron	1.23 }	
Titanium	0.06	1.00 ²
	98.12	100.00

In this area are strata of high grade limestone and less than a mile distant is a belt of Martinsburg shale so that the necessary materials for Portland cement are near together. This shale is high in silica as shown by the following analysis:

Silica	69.24
Alumina	14.70
Ferric iron.....	2.52
Ferrous iron.....	1.68
Magnesium oxide.....	1.07
Lime oxide.....	0.41
Sodium	1.41
Potassium	3.93
Water	0.30
Titanium	1.69
Phosphorus	0.43
Loss on ignition.....	2.27
	99.65

A large electrical power plant has been contracted for on the Shenandoah river about one mile from the marl deposit and would furnish light and power to mills in this vicinity. Marls are looked upon with much favor by many cement engineers, and these deposits in Jefferson and Berkeley counties are the only large deposits as yet located in the State. The Baltimore & Ohio railroad, Shenandoah division, reaches this section at Millville, and a mile and a half of siding would reach the marl deposits.

Other Locations in Jefferson and Berkeley Counties.

The Shenandoah limestone covers most of the area of Jefferson and Berkeley counties, and in many places is suitable for Portland cement manufacture, but the shales or clays are not always

1. Geol. Survey of Mich., Vol. VIII., p. 283.
2. Organic matter, water and sulphuric acid.

present and in such localities the extra cost of transportation of raw material as a source of silica and alumina would rule out the locality in favor of those areas where all the necessary materials are found. Among the other possible locations for cement mills are Engles, Bakerton, Bunker Hill, Shenandoah Junction, but the conditions at these places are not as favorable as those already described.

At Engles, the shale would come from the top of the hills to the northeast, requiring a tram or overhead cable haulage of nearly a mile in length. At Bakerton the red clay to be used with the lime contains 7 per cent. of ferric oxide, which is rather high, otherwise the clay contains the correct proportions of silica and alumina, and is present in large quantity. Some parts of the deposit reach 25 feet in thickness.

Bunker Hill is located on the Cumberland Valley road and would require transfer of cars to reach the eastern markets. Near this place good limestone, shale, and marl, are found, and if the eastern freight rates are made the same as over the main lines this would be a good cement location.

The composition of the limestones in these sections is given in the following table:

	New Potomac quarry.		Old quarry.	
	Engles.	Engles.	Bakerton.	Bunker Hill.
Lime carbonate.....	92.27	98.21	95.55	97.05
Magnesium carbonate..	3.18	0.86	2.44	1.85
Silica	1.18	0.02	0.12	0.59
Iron and alumina.....	1.60	0.75	1.01	0.47
Sulphur	0.51	0.09	0.15	....
Phosphorus	0.08	0.007	0.02	....
	98.82	99.937	99.29	99.96

In the new Potomac quarry of Keller Brothers, at Engles, there are belts of a peculiar white shale or slate which has a smooth, soapy feel and form belts 20 to 50 feet wide. The analysis shows that this mineral is probably a magnesian silicate. On account of its high percentage of magnesia and low alumina percentage, it would not be available for cement mixtures, as has been suggested by some who have examined the quarry. Its composition and that of the red clay at Bakerton are shown in the following analyses:

	Engles.	Bakerton.
Silica	42.95	55.43
Alumina	9.13	18.78
Ferrie oxide.....	1.02	7.06
Ferrous oxide.....	1.00	0.15
Magnesium oxide.....	12.15	2.59
Lime oxide.....	11.40	1.56
Sodium	0.39	0.12
Potassium	5.50	0.69
Water	2.02	2.62
Titanium	0.37	0.60
Phosphorus	0.77	0.60
Sulphur	none	1.05
Loss on ignition.....	13.15	9.13
	99.85	100.38

KEYSER, MINERAL COUNTY.

Near Keyser, on the Baltimore & Ohio Railroad, the Lower Helderberg limestone outcrops in bluffs, 200 feet high, with practically no cover. The rock is nearly vertical, with dip to the west. The rock breaks with smooth vertical joint planes, which are prominent features in these quarries, as the smooth wall of rock, 200 feet high, can be seen for a long distance. Some of the rock is shaly, and it varies in color from white and gray to nearly black. In the railroad quarry an 18-foot belt of flint rock comes into the series.

The Standard Lime and Stone Company opened five years ago a large quarry one mile east of town, crushing the rock for railroad ballast. On the county road one-half mile from town is the Keyes quarry, opened for building stone. Some years ago this stone was quarried at a number of points, and burned for lime.

The composition of the Keyser limestone is shown by the following analyses:

	No. 55.	No. 179.
Lime carbonate.....	93.89	98.94
Magnesium carbonate.....	1.32	0.68
Silica	1.85	0.49
Iron and alumina oxide.....	1.45	0.40
Sulphur	none	....
Phosphorus	0.05	....
	98.56	100.51

No. 55 is from the Standard Lime & Stone Company quarry, one mile east of town, on B. & O. railroad.

No. 179 is from the Keyes quarry on county road, one-half mile east of town.

These limestones are of high degree of purity and adapted to Portland cement manufacture. The ledge sampled in the Keyes quarry was 20 feet wide and 50 feet high in the quarry, but it doubtless goes to greater depth. From the appearance of the rock in this quarry all the rock exposed would probably be adapted to use in cement.

About one-half mile from the limestone comes the shale area. This shale has the following composition:

Silica	73.30
Alumina	10.61
Ferrie iron.....	6.23
Ferrous iron.....	1.94
Magnesium oxide.....	1.06
Lime oxide.....	0.11
Sodium	0.24
Potassium	1.49
Water	0.47
Titanium	0.85
Phosphorus	0.30
Loss on ignition.....	3.34
	99.94

The silica-alumina ratio is too high in this sample for use in cement, but further investigation might reveal suitable material or it could be shipped from other places.

There is a large area of these cement materials which can be worked in open quarry with little or no cover. They are easily reached by the Baltimore & Ohio and by the West Virginia Central Railroad. Fuel supply could be brought in by both railroads.

HENDRICKS, TUCKER COUNTY.

About five years ago Mr. R. P. Pearson, a civil engineer then in the employ of the Weaver Coal and Coke Company, being impressed with the advantages of a tract of limestone land, one mile from Hendricks on the Dry Fork Railroad, purchased the same and started a small lime industry, which proved very profitable. Through some difficulties in the company which was organized the property was thrown into a receiver's hands and the work stopped. While the case has practically been settled the property has not yet been reopened.

This location is one which possesses special advantages as a cement proposition and affords an opportunity for a single

company to nearly control the entire field in this part of the state on account of the topography.

The stream known as Dry Fork has a narrow valley with steep bluffs at the side, but where it cuts through the limestone one mile from Hendricks, the east bank has a level flood plain for a distance of nearly one-half mile, affording sufficient space for the erection of a large plant, and at this point the lime kilns were erected. The Dry Fork Railroad runs along the edge of this space, and a mile away at Hendricks connects with the West Virginia Central & Pittsburg Railroad, which gives a direct route to Baltimore and later will reach Wheeling and the west.

While the name of the river would suggest an uncertain water supply, this is not the case, as the river has a considerable volume of water at all times of the year, and by building a dam sufficient water would be available for a large cement mill. The tract, which can be purchased on reasonable terms, contains nearly 500 acres, with limestone, natural cement rock, clay, shale, coal and timber.

Limestone. The limestone is of Lower Carboniferous age, known as the Greenbrier, which extends across the State from north to south. Its thickness is unknown, but has been estimated as 400 to 500 feet. Actual measurement of the present outcrop shows 325 feet. While the rock varies in composition the greater portion of it is suitable for Portland cement. Near the top of the limestone outcrop is a natural cement rock, which is about 20 or 25 feet in thickness, with the following composition according to the analyses of R. W. Hunt & Co.:

	No. 1.	No. 2.
Lime carbonate.....	32.17	38.83
Magnesium carbonate.....	18.36	16.30
Silica	38.93	36.60
Iron and alumina.....	4.17	6.33

The lime quarry was opened 150 feet above the kiln floor, and a twelve-foot face was worked. Forty-five feet lower is an old cave, which is 60 feet deep and limestone to the bottom. At this place, then, a quarry could be opened with a face of 120 feet, but this could be increased above by an additional face of probably 150 feet of good limestone. The slope of the hill in this part of the tract would enable a company to work the quarry into the hill 400 or 500 feet before any expensive removal of

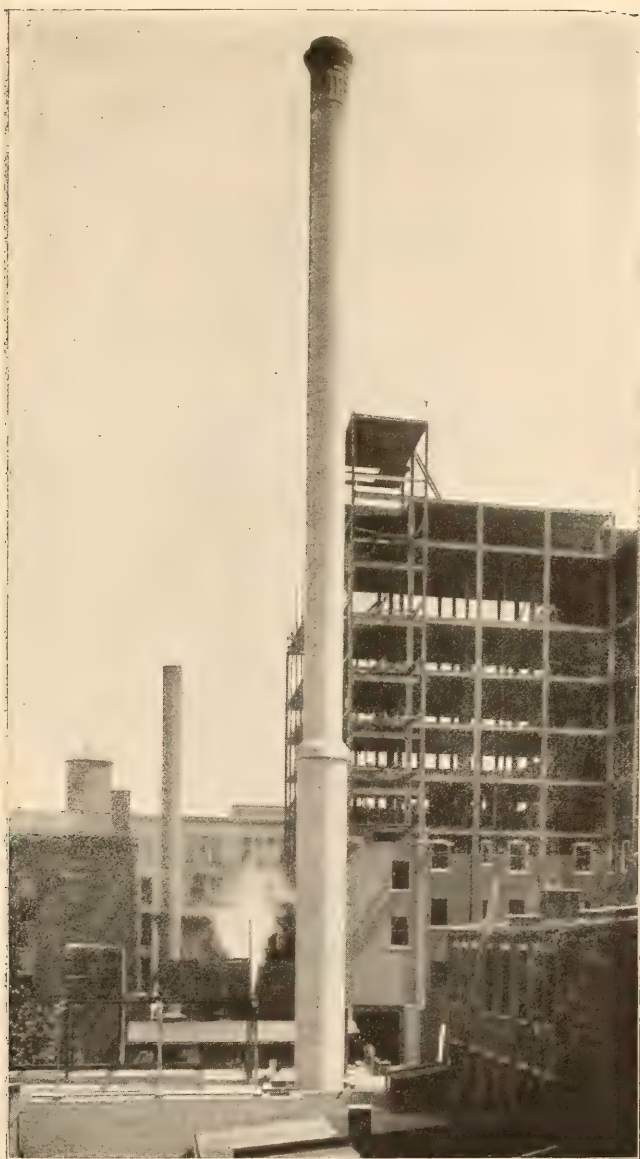


Plate XLII.—Reinforced Concrete Chimney at Louisville, Kentucky.
(From "Concrete.")

cover would be required, and a length of at least 600 feet. There is thus in sight at a conservative estimate 2,000,000 cubic yards of good limestone, which would last a 2,000-barrel plant a couple of centuries. If the estimate is lowered one-half there is still sufficient rock to justify the location of a mill.

The composition of the limestone taken from sections 40 or 50 feet apart in vertical distance is shown by the following analyses, the first by J. C. Brydon and the second by George P. Maury:

	Lower.	Upper.
Lime carbonate.....	92.53	89.16
Magnesium carbonate.....	2.15	1.93
Iron and alumina oxides.....	0.58	2.43
Silica	4.74	6.86
	100.00	100.38

Shale and Clay.—Over the limestone on the hill back of the quarry is a mass of red shales, at least 200 feet in thickness, known as the Mauch Chunk shales. In places these have slipped and form six to ten feet of cover over the limestone on the slopes below.

The valley below the quarry near the lime kilns, and the lower slopes of the mountain, are covered with a red clay two to twenty feet in thickness, which has resulted from the weathering of the shales above. The composition of the shale and clay are given in the following analyses by George P. Maury:

	Shale.	Clay.
Silica	57.88	67.10
Alumina	15.80	18.74
Iron oxide.....	4.81	5.14
Lime carbonate.....	16.86	....
Lime oxide.....	....	0.96
Magnesium carbonate.....	2.08	....
Magnesium oxide.....	....	0.96
Water	2.72	4.69
Sodium .....	....	2.40
	100.15	99.99

The silica-alumina ratio in the shale is 3.66 and in the clay 3.52, thus coming within the proper ratio limits. Calculating the proper mixtures according to the method given in chapter XVII, would give with the upper limestone and shale one part of shale to 5.355 parts of limestone, or 100 parts of shale to 535½ parts of limestone. The limestone-clay mixture should be one part of

clay to 6.559 parts of limestone, or 100 parts of clay to 656 parts of limestone.

These materials were tested by Geo. P. Maury, of the Pittsburgh Metallurgical Laboratory, who used nearly the same proportions as calculated above. The following analyses are taken from his report and he classes the cement as high-grade.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Silica	23.70	22.29	22.20	22.35	22.89
Alumina	6.42	6.39	6.72	5.51	8.00
Iron oxide	1.71	1.52	2.28	2.76	2.44
Lime	67.47	67.83	67.31	65.52	63.38
Magnesia	1.70	1.44	0.95	1.24	2.50
Alkalies .....	....	0.45	....	0.92	....
Sulphur	none	none	0.26	1.69	....

No. 1 was made from a mixture of 11 parts of limestone and 2 parts of shale.

No. 2 was from a mixture of 7 parts of limestone and 1 part of clay.

No. 3 is an analysis of French Portland cement.

No. 4 is an analysis of German Portland cement.

No. 5 is an analysis of an American Portland cement.

The analyses Nos. 1 and 2, in comparison with the other analyses of well known grades of cement which stand in high favor, show that good cement can be made from these Hendricks materials.

Fuel.—This locality is near some of the large coal mining centers, and coal could be obtained from these mines at a very low cost. It is not necessary in this proposition to go away from the limestone tract for fuel for power and heat, a feature which adds still more to the value of this location and makes it unique among possible locations, not only in this State, but in this part of the country. On the same tract one finds the cement materials and coal fuel.

Six hundred and fifty-five feet above the limestone, 875 feet above the present small quarry, or 1,050 feet above the railroad track are found the coal mines, in which the coal reaches $4\frac{1}{2}$ feet. The entry has been driven a couple hundred feet to the northeast and shows a bright, glistening coal, with a roof of black slate filled with plant remains.

The coal has been opened in three places and is found 220 feet below the 30-foot layer of Pottsville conglomerate at the top of the hill. Another coal is reported at 140 feet above the mine. The section at this place shows a thickness of 580 feet for

the Pottsville series, as compared with 150 to 300 feet in Ohio and Pennsylvania, while the thickness farther south on New river is 1,400 feet.

This coal has been classified as Clarion in two expert reports, but since the Clarion should come above the conglomerate, this coal could not be that seam. At the time this area was examined the slope of the mountain was covered with dense vegetation, and the rock in the small ravines was concealed by debris, so that a careful inspection could not be made, and the correlation of this coal with those to the south was impossible. Its position cannot be far from that of the Nuttall or Sewell seam of the New River series.

A timber chute lined with steel plates and 1,200 feet long leads from the coal mine to the incline track, which is 1,500 feet long to the lime kilns. This incline has steel rails and is connected by side inclines with the quarry. The chute in its steepest slope is inclined at an angle of nearly 45 degrees, and the incline track at an angle of 28 degrees. Both incline and chute are constructed of heavy timbers and could be placed in good repair at very small cost.

The coal at the mine has the following composition, according to analysis of the chemist of the Davis Coal and Coke Company:

Moisture	0.95
Volatile combustible matter.....	24.81
Fixed carbon.....	68.18
Ash	6.08
Sulphur	0.48

100.50

The coal is low in sulphur and moisture, and contains 92.99 per cent of combustible matter. It is a good steam and fuel coal, but its low percentage of volatile matter would probably prevent its use in the rotary kiln, which requires a coal of about 30 per cent or more volatile matter, though some engineers place the required percentage as low as 25. If the latter figure should prove correct, this coal could be used for burning the cement. The cost of delivery of this coal at plant was only 62 cents per ton, and if it could be used in rotary kilns would make a fuel cost of 6 cents a barrel. Natural gas has been brought by pipe line to

Hendricks, one mile from this location, and could be used in the rotary kilns.

Lime Industry.—The limestone quarry at this point was opened to supply the kilns in the manufacture of lime. There are two nine-foot Coleman steel lime kilns, and the material for a third. Each has a tested capacity of 350 bushels (of 80 pounds) of lime per day. There are five tanneries and three pulp mills in this vicinity, making a large demand for lime, which is now supplied from Ohio, Maryland and Pennsylvania, with a freight cost of 11 to 15 cents a bushel, so that the lime costs in car load lots 23 to 26 cents per bushel.

When this plant was in operation it was found that lime could be made and sold at 15 to 18 cents per bushel, with a large profit. Twelve car loads of lime were made and used by the Parsons paper and pulp mills, proving satisfactory in all respects. The large plants in this region use about twelve car loads of lime a week. There is also an extensive building trade market in this section. The lime industry could be carried along with the cement industry, adding materially to the profits of the company.

An analysis of the Hendricks lime burned at this plant was made by the Chicago Bureau of Inspection and Tests.

Lime oxide.....	93.21
Magnesium oxide.....	3.18
Iron and alumina oxides.....	1.06
Silica	2.55

100.00

Summary.—This location is almost an ideal cement proposition, with necessary materials for Portland cement tested showing they make a cement equal to the best grades on the market. Coal fuel on the cement land and natural gas a mile distant, good water supply, building site and railroad connections, topography which makes this location practically a monopoly on the whole district. Unlimited quantity of raw materials and the great opportunity in lime trade as an addition to the cement industry. A tract with the preliminary development work completed as a cost of \$32,000, which can be purchased at a very low cost. This property should not be permitted to go without development, when its advantages are once known by capitalists wishing to secure a large interest on their investment.

POCAHONTAS AND GREENBRIER COUNTIES.

The Greenbrier limestone, which has a thickness of 400 to 500 feet in Tucker county, reaches 1,000 to 1,400 feet in the southeastern part of the State. It covers wide areas in Pocahontas, Greenbrier, Webster, Summers and Monroe counties. This is the great limestone area of the State, both in thickness and extent.

While at the present time a large portion of this limestone is without railroad connections, there remain large tracts close to the railroad, and many of the railroad cuts are made through it, as shown in plate XXXVIII. The limestone has been opened at a few places for building stone. It is burned for lime at Snowflake, near Fort Spring, Greenbrier county, and near the same place is a large railroad ballast quarry.

Near Marlinton and other places are large caves, with strong streams of water coming from them, locally called Big Springs, and probably representing the outlet of subterranean streams. The Chesapeake & Ohio Railroad main line and Greenbrier branch give access to this limestone, and would furnish an outlet to cement and lime that might be made in this part of the State.

The character of the limestone in Pocahontas and Greenbrier counties is shown by the following analyses:

	No. 175.	No. 176.	No. 177.	No. 180.	No. 181.	No. 182.
Lime carbonate...	87.93	97.73	71.34	82.77	92.88	83.51
Magnesium carbonate	4.00	1.44	8.49	11.41	2.79	10.56
Silica	4.97	0.89	15.62	4.93	3.74	4.61
Alumina	1.89	0.61	3.60	1.64	1.31	1.44
Iron oxide.....	0.93		1.53			
Titanium	0.05	....	0.12	....	....	....
	99.77	100.67	100.70	100.75	100.72	100.12

No. 175 is the blue limestone from Frazier quarry two miles west of Fort Spring.

No. 176 is the oolite from Frazier quarry.

No. 177 is the so-called Pocahontas marble near Marlinton.

No. 180 is the limestone near the marble.

No. 181 is from Lewisburg quarry.

No. 183 is from west of Marlinton.

These analyses show a variation in the rock in different parts of the area. The limestone sampled near Marlinton gives high percentages of magnesia, but in all probability a more detailed study would locate a good grade of rock for cement man-

ufacture. The Lewisburg and Fort Spring limestones are quite pure, especially the oolite.

Shale and Clay.—River clays are found in the valleys, and have been used on a very small scale in the manufacture of brick. Shale deposits are found in a number of places. One deposit was sampled near the Frazier limestone quarry, and might be used with the limestone for a Portland cement mixture. It is a lime shale, with high percentage of alumina and silica.

Silica	42.55
Alumina	15.15
Ferric oxide.....	1.74
Ferrous oxide.....	2.67
Magnesium oxide.....	2.11
Lime oxide.....	15.48
Sodium oxide.....	0.82
Potassium oxide.....	2.73
Water	0.76
Titanium	0.63
Phosphorus	0.37
Loss on ignition.....	15.18
	100.19

This area with a trunk line railroad, nearness to large coal fields and good water supply, deserves attention from capital. In this section may be found the best locations for Portland cement mills in the southern part of the state. The quantity of available rock is almost unlimited, the Frazier quarry is worked with a face 125 feet high, and the rock can be quarried and crushed at a cost of about 25 cents a ton. The limestone near Marlinton shows a vertical thickness of at least 250 feet above the river valley.

MORGANTOWN, MONONGALIA COUNTY

The Greenbrier limestone is found in an isolated outcrop on Decker's creek, twelve miles above Morgantown, on the Morgantown & Kingwood Railroad, between the stations of Oliver and Lick Run. The length of this outcrop is about four miles and width probably two miles.

Limestone.—The outcrop on the hills near Lick Run shows 100 feet of limestone, which is quite sandy near the base. This limestone has been examined very carefully and twenty-five

analyses have been made. A few of these are given to show the character of the rock.

	No. 116.	No. 117.	No. 118.	No. 119.	No. 121.
Lime carbonate.....	78.28	86.84	94.98	26.58	96.13
Magnesium carbonate.....	1.51	2.11	1.38	0.71	0.49
Alumina	4.61	2.26	0.75	4.48	1.12
Iron oxide.....	2.16	1.00	1.03	1.34	0.51
Silica	12.64	8.28	3.31	62.96	2.47
Titanium	0.15	0.12	0.04	0.22	0.01
Sulphur	0.02	0.04	0.38	0.02	0.01
	99.37	100.65	101.87	96.31	100.74

No. 116 is near the top of the small quarry above Lick Run station, and near the county road.

No. 117 is eight feet lower in the quarry.

No. 118 is near the bottom of the next quarry, and would come above the top of the first quarry.

No. 119 is the sandy layer near the bottom of the limestone and above the Pocono sandstone just below and across the creek from Sturgiston.

No. 121 is east of Lick Run and above the railroad track, representing the purest limestone of the series.

Other analyses of the sandy layers near the bottom of the limestone gave low percentages of alumina, and it is very doubtful whether a cement mixture could be made from the different layers of limestone. In order to secure the proper percentage of alumina it would be necessary to use a small amount of clay or shale. The limestone in two vertical sections sampled every ten feet was found to be adapted to use in Portland cement mixtures.

Shale and Clay.—The Mauch Chunk red shales are found in this area in good thickness, and the valley below contains deposits of red clay of good extent and thickness. The analyses below show a high iron percentage, and if this should prove injurious the coal measure buff shales could be used from places east and west of this location.

	Shale.	Clay.
Silica	56.30	71.38
Alumina	19.07	12.89
Iron oxide.....	9.58	5.77
Magnesium oxide.....	2.01	0.62
Lime oxide.....	0.69	0.40
Water and loss on ignition.....	8.01	6.74
Titanium	0.71	0.88
	96.37	98.68

Advantages of Location.—By building a dam across Decker's creek there would be a good supply of water for the mill. There is a large level tract below the hill for a good building site. The Morgantown & Kingwood Railroad now gives close connection with the Baltimore & Ohio Railroad at Morgantown, and it will soon be connected with the B. & O. at Rowlesburg, giving a short route to eastern markets. River connection is gained at Morgantown, so that cement could be shipped by boat to Pittsburg and the towns and cities along the Monongahela and Ohio rivers. The former stream is provided with dams and locks, making it navigable for large boats.

Natural gas fuel has been brought beyond Morgantown and could be piped to this location. It is sold for manufacturing purposes at five cents a thousand cubic feet. Coal mines are in operation above and below this location. The Decker's Creek coal has the following composition, according to the analyses of the State Geological Survey:

Volatile combustible matter.....	30.97	30.02
Fixed carbon.....	59.95	60.43
Ash	7.53	8.23
Moisture	1.55	1.32
Sulphur	0.89	1.11
British Thermal Units.....	14008	14002

The Pittsburg coal from the Fairmont region can be laid down at the mill for \$1.25 a ton, so the company would have the choice of local coal, Pittsburg coal or natural gas.

Morgantown, with its glass works, tin plate mill and brick plants, is developing into a manufacturing city, and it will not be long before this Portland cement location will attract attention and a mill be erected.

CHEAT RIVER, MONONGALIA COUNTY.

The Greenbrier limestone is exposed along Cheat river six miles east of Morgantown, but at the present time is not reached by the railroad. The new cut-off surveyed by the Baltimore & Ohio Railroad would pass through this area, and it would then prove a valuable location.

The limestone at this place has the following composition in the upper 25 feet sampled from top down:

	No. 96.	No. 97.	No. 98.	No. 99.	No. 100.	No. 101.
Lime carbonate.....	84.38	88.39	90.92	91.61	81.32	92.48
Magnesium carbonate...	2.36	3.28	2.51	1.61	4.57	2.46
Silica	8.90	5.84	3.92	4.20	8.82	3.52
Alumina	2.43	1.54	1.13	1.29	2.96	1.19
Iron oxide.....	1.26	1.26	0.88	0.76	1.26	0.75
Titanium	0.14	0.07	0.06	0.07	0.14	0.04
Phosphorus	0.065	0.055	0.055	0.045	0.045	0.06
Sulphur	0.03	0.05	0.06	0.03	0.04	0.03
	99.565	100.485	99.535	99.615	99.155	100.53

The analyses of this section show a high-grade limestone, which could be used for cement. The Mauch Chunk red shales are found in the same area. The only Portland cement mill in the state is located 25 miles up Cheat river from this place, and is using the Greenbrier limestone.

SCOTT'S RUN, MONONGALIA COUNTY.

Scott's run empties into the Monongahela river three miles northwest of Morgantown, opposite the town of Randall. Near the mouth of the creek the Pittsburg limestones are exposed, but the layers are not of any great thickness, and the rock is quite impure, the lower ledge being very high in iron. The Pittsburg coal is mined a short distance up the creek and underlies nearly all this region. Ten to twelve feet above the coal is the Redstone limestone 18 feet in thickness, with the Redstone coal above, and 75 to 100 feet higher is a series of limestone layers separated by shales about 100 feet in thickness, known as the Uniontown limestone.

Over the Redstone coal is a fine shale 15 to 20 feet in thickness, and then 6 feet of limestone. In this area are shales, limestones and coal. While the Redstone limestone is not very thick (18 feet) it outcrops around the hills over a large acreage, so that the quantity would be large, and followed around these hills the cover would not be too heavy for profitable quarrying.

The chemical composition of these limestone is shown by the following analyses:

	No. 122.	No. 125.	No. 126.
Lime carbonate.....	79.63	86.70	83.52
Magnesium carbonate.....	1.44	5.32	3.78
Silica	12.21	5.96	10.54
Alumina	2.87	1.01	0.75
Iron oxide.....	2.36	1.27	2.06
Titanium	0.15	0.07	0.05
	98.66	100.33	100.70

No. 122 is the Redstone limestone.

No. 125 is near the top of the Uniontown limestone.

No. 126 is the 6 to 8 foot limestone above Redstone coal.

A mill could be built near the river and the cement be loaded directly into boats, or an overhead cable could carry the cement across the river to the Baltimore & Ohio Railroad.

For fuel, the Pittsburg coal could be mined by drift or shaft over the whole area, the other coals would be available as fuel for power. The natural gas pipe lines cross the tract and gas would cost 5 cents per 1,000 cubic feet.

OTHER LIMESTONE DEPOSITS.

Reference to chapter XIV. of this report will show that a large number of limestones are found in the Coal Measure group of rocks in West Virginia. Some of these limestones are found on analysis to have a high degree of purity and are adapted to use in Portland cement mixtures, but the strata are not usually thick enough to justify the location of a cement mill.

In a preliminary report like the present one it was not possible to examine in detail all sections of the State, or even to follow the great belts of limestone throughout their length. A special effort was made to study the most favorable localities, and these have been included in the present chapter. It is not only possible, but probable, that some good cement locations have been overlooked, but a careful study of the descriptions in this chapter will show the very great possibilities of the cement industry in this State, and there is reason to believe that in a few years Portland cement will be one of the important sources of revenue in West Virginia.

In the progress of this work the writer has made public, through the newspaper press, the results of the investigation in different localities. There has resulted considerable interest in the subject on the part of capital, and numerous requests for further information have been received from this and other states. As a direct result of this work three companies are now seriously considering the construction of Portland cement mills at some of the above described locations, and have purchased land for cement development. It is hoped that the publication and distribution of this volume to all parts of the country will arouse an active interest in this subject and thus promote the welfare of this State.

CHAPTER XXII.

THE USES OF PORTLAND CEMENT.

The growth of the cement industry in this country during the past decade has been one of the marked features of the mineral industry. In 1895¹ 990,324 barrels of Portland cement were manufactured in the United States, and 2,997,395 were imported, making a total of 3,087,719 barrels used in this country for various purposes. In addition nearly 8,000,000 barrels of natural cement were made.

In 1904¹ the total production reached 26,505,887 barrels of Portland cement, and 968,490 barrels were imported, making a total of 27,474,290 barrels, but 774,940 barrels of cement were exported, so that the total amount used in this country in 1904 was 26,699,350 barrels. There are 83 Portland cement mills located in 17 states, and Pennsylvania, with 17 plants, is the leading state in production, making 40 per cent of the total product. There are 61 natural cement plants and the production in 1904 was 4,886,331 barrels.

The cause of this remarkable growth in the cement industry has been the increased variety of uses, especially its use as a substitute for other building materials, lumber, brick and stone. Some writers go so far as to state that the country is entering a new structural stage, the "Age of Cement." To those who have not followed the subject closely the variety of uses of cement will be a matter of surprise.

The building of new cement mills, often of large size, over the country, resulting in the great increase of supply, would seem to be out of profitable relation to demand, but these new plants are found for the most part to be successful, and they are able to dispose of their output, and the work of planning and locating new mills goes on.

1. Statistics from U. S. Geol. Survey, Mineral Resources.

The present chapter describes some of these uses which have so greatly increased the demand. It is not intended as an original chapter, but a careful compilation from the various reports and technical journals. Those especially used as sources of this information are: "Concrete," of Detroit; "Rock Products," of Louisville; "The Cement Age," of New York; "Cement and Engineering News," of Chicago; "The Engineering News," and the Ohio Geological Survey report on "Uses of Cement" by Eno. The object of the chapter is not to give a complete and detailed account of the uses of cement, but to give a general discussion of the subject for the benefit of the people of this State who are interested in the development of their mineral wealth, but have not access to these various sources of information.

CONCRETE.

Concrete is defined as a mixture of cement and aggregate composed of coarse and fine material. This foreign material may be cinders, sand, gravel, finely crushed rock, or broken rock. The proportions of the mixture will vary with the character of the work and the plans or judgment of the workman. The proportions vary ordinarily from one part cement, two parts sand, and five parts broken stone, to one part cement, four parts sand and eight to ten parts broken stone or gravel.

According to Sabin¹ the value of the added material or aggregate depends on at least six characteristics: The strength and durability of the stone, the size and shape of the fragments, the volume of the voids or open spaces in the aggregate, and the character of the surface of this material to which the cement must adhere.

On account of the more uniform shapes of gravel and the more varied range of sizes, than in crushed rock, there is usually a smaller percentage of voids, giving roughly 30 to 37 per cent of voids in gravel as compared with 40 to 50 per cent in broken stone. Gravel and cement will thus give a more compact concrete with a smaller amount of cement than the mixture of broken stone and cement, but the angular fragments of the stone will knit together, forming a stronger concrete. Sabin concludes

1. "Cement and Concrete," quoted in *Concrete*, Vol. 4, No. 2, p. 14.

that the question of material is to be determined more by relative cost of the materials and their suitability to the work in hand.

There are two methods of mixing concrete—the dry method, where just as little water as possible is used in the mixture, and the wet method, where an excess of water is used. A third medium method is sometimes given, using a very slight excess of water. In the dry method the mixture is usually consolidated by pressure or tamping. In the wet method the concrete is poured into the molds. Concrete building blocks are usually made by the dry or medium methods and concrete foundations by both methods.

A series of experiments were made by James W. Sussex on the relative advantages of wet and dry mixtures for general use, and the results of his experiments were as follows¹:

1. There is no condition of age or amount of tamping which shows dry concrete to be the strongest.
2. Dry concrete should never be used.
3. Medium concrete may be used where immediate strength is desired.
4. Wet concrete is stronger than either dry or medium at any age over three months.

In the use of sand in concrete it is not always possible to secure a clean, sharp, coarse sand, as demanded in many specifications. River and drift sands contain a considerable percentage of clay or loam, which has often been considered detrimental to good concrete work. Experiments have been made along this line in a number of laboratories and the tests show no bad results from small percentages of loam or clay in the sand. Prof. W. C. Hoad, of the University of Kansas, conducted an extended series of tests on clay and loam mixtures with cement², and from a study of these tests concluded that the presence of loam or clay in the small amounts found in river sands (2 to 10 per cent) did not detract from the strength of the mortar, but added to it. Tests of absorption showed that one to three mortars made with sand containing up to five and six per cent of clay or loam were as dense as those made with clean sand. Similar experiments in other laboratories have led to the same conclusions.

1. Concrete, Vol. 1, No. 3, p. 9.

2. Kansas Acad. of Science, Vol. XIX., p. 81; 1905.

Concrete has long been used for the foundations of large and small structures. It can be placed rapidly and cheaply. In a few days it is ready for the superstructure. A concrete foundation setting as one piece makes a stronger building, especially in areas where it is impossible or too expensive to reach solid rock or ground. Railroad bridge abutments and retaining walls are now largely made of concrete.

CEMENT SIDEWALKS.

Artificial stone sidewalks represent a large use of cement. They give a smooth, durable walk, which is economical and pleasing to the eye. According to L. L. Bingham¹ a walk four inches in thickness will cost approximately:

Average cost of sand and gravel per square foot.....	1 1-2 cents
Average cost of cement (\$2.00 per barrel).....	3 3-5 cents
Average cost of labor.....	2 1-5 cents
Average cost of incidentals.....	.006 cents
Total.....	8 cents

The average selling cost is 11 to 15 cents per square foot.

It is important to have a solid foundation for the walk, made of broken stone, cinders or gravel. On this is spread the concrete three to four inches thick, made of one part cement to two parts sand and four or five parts broken stone or gravel. The wearing surface, about one inch thick, is made with one part cement and one part sand, or one part fine rock screenings, and spread over the concrete before the latter is dry. The top surface is floated or troweled smooth and cut into blocks with a wedge-shaped tool at four to five feet intervals to allow for expansion and contraction. Some engineers insist that the blocks should be cut through the concrete as well as the wearing surface layer for the best results.

According to P. B. Berry² the cement sidewalk may be colored as follows:

Black by using 2 per cent Excelsior lamp black.
 Red by using 10 per cent best raw iron oxide.
 Brown by using 6 per cent best roasted iron oxide.
 Blue by using 6 per cent ultramarine.

1. Concrete, Vol. III., No. 3, p. 21.

2. Cement and Eng. News, May, 1903, p. 85.

Concrete is also used for curb and gutter work by being molded in place or in form of blocks, which may be set in proper position. It can be made in one piece, giving a finished appearance to a paved street, and the smoothness of finish of the gutter gives an unobstructed flow to the water. Cement in this form has proved durable and an improvement over many kinds of stone formerly used. The cost of combined curb and gutter runs from 70 to 85 cents a foot, and it is becoming very popular in many cities.

CEMENT STREET PAVING.

Concrete has been used in a number of places for street paving, and there has proved a strong competitor with asphalt. It may become in the near future an important paving material. According to F. H. Eno¹, four streets in Bellefontaine, Ohio,

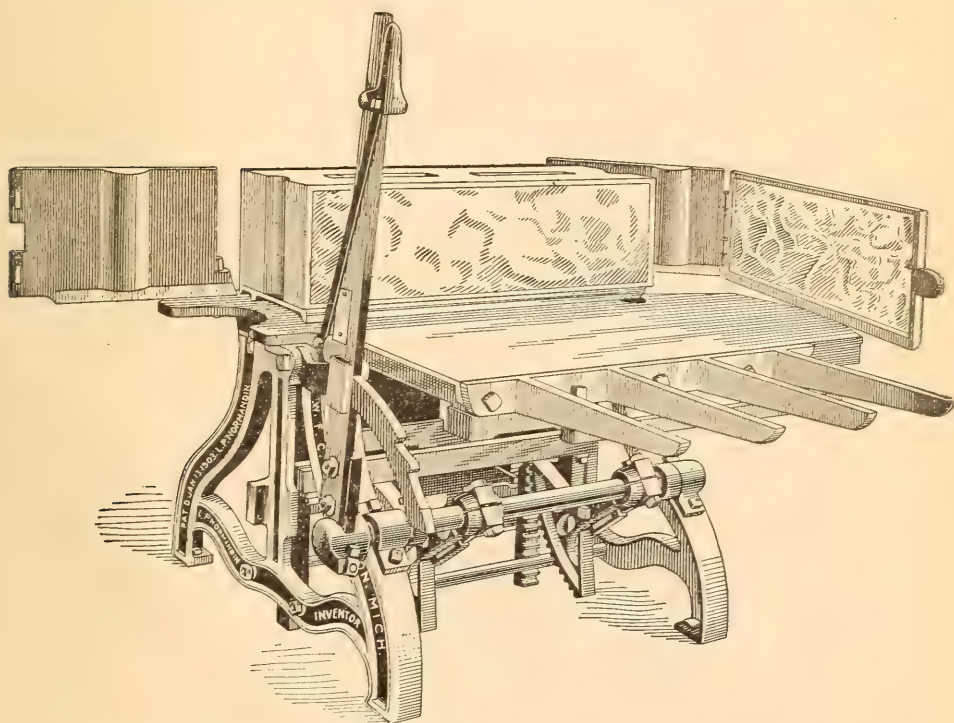


Fig. 51.—Normandin Concrete Building Block Machine.

1. Ohio Geol. Survey, Bull. No. 2, p. 111.

were paved with concrete in 1892 and 1893 and are in good condition at the present time. The concrete was laid upon a good roadbed in two layers, the foundation layer four inches thick and surface layer two inches. The foundation concrete was composed of one part Portland cement to four and five parts coarse gravel, while the surface coat was three parts cement to five parts coarse sand on two of the streets, and one part cement to one part sand on the other two. Both layers were cut into blocks five or six feet square to give room for expansion. The streets have worn well, are not slippery, are easily cleaned, and soon dry off after storms. The cost of construction was \$2.15 a square yard.

In Le Mars¹, Iowa, one street has been paved with concrete as an experiment. The lower course is five inches thick, made of one part cement to six parts gravel. The upper course, one and a half inches thick, is composed of one part cement to two parts coarse sand, and is grooved three-eighths inch in depth every four inches to give foothold for horses in winter or wet weather. After three months' wear, under average traffic, the street is still in good condition.

Cement paved streets have been laid in Richmond, Indiana, at a cost of \$1.50 a square yard. In Toronto, Canada², the cement roads are made with a four-inch concrete foundation and two and a half inch wearing surface. The mixture consisted of one part cement to one part sand and three parts fairly coarse crushed granite. The surface has deep grooves, cutting the pavement into five and ten inch blocks to give better foothold. Cement concrete has also been molded into blocks for street pavements.

Mr. O. L. Gearhart, city engineer of Champaign, Ill., has made a number of experiments on the use of cement as a filler in brick paved streets.³ He found that the strength of the pavement was greatly increased and the additional cost over a sand filler was six to ten cents a square yard.

1. Concrete, Vol. II., No. 5, p. 19.

2. Eng. Record, Vol. 50, No. 20, p. 560.

3. Eng. News, Vol. 51, No. 5, p. 114.



Plate XLIII.—The Longest Concrete Arch Bridge in the World.

Carrying the tracks of the new San Pedro, Los Angeles & Salt Lake Railroad across the Santa Ana River, near Riverside, Cal. The bridge consists of ten arches each of 86 feet clear span ; its total length is 1,000 feet ; and its height 60 feet. 25,000 tons of concrete were used in its construction.

CONCRETE BUILDING BLOCK INDUSTRY.

In the last few years the manufacture and use of molded concrete hollow blocks have become quite general over the country. There are very few towns and cities that do not have some examples of this construction. Practically every city in West Virginia has a branch of this industry established, though the use of the blocks varies in popularity. In some sections, where blocks of faulty construction have been used, they are looked upon with disfavor, while in other sections the industry is well established.

The successful use of concrete blocks in so many towns and cities, the ease of manufacture, the low cost of equipment for the work, and the rumors of great profits, have led many people with little or no experience to enter the field, and by their careless work, resulting in low strength blocks, have done great harm to the industry. In a town where two or three buildings have been built of these poor blocks, their cracked and chipped appearance make a poor advertisement of the industry, and greatly hinders the use of blocks made in the proper way by a careful company.

At the present time there are over 100 cement block machines on the market, and over 4,000 makers of the blocks. There has recently been organized a Concrete Block Machine Manufacturers' Association. These different machines have their ardent defenders, so that a person entering upon this work and trying to select the best machine is confronted on all sides by advertisements and testimonials, showing how each of the 100 machines is better than all other types. There probably is no best machine, but a large number of excellent machines for this work, and possibly a few poor ones. Two types of concrete block machines are shown in figures 51 and 52. The first patent issued on a concrete block machine was to H. S. Palmer, of Washington, D. C., in 1889, and for twelve years this was the only machine on the market.

The advantages of cement building blocks are set forth as follows by one of the machine companies:¹

1. Winget Machine Catalogue, Columbus, O.

Concrete blocks make a building cost less money; the building is warmer in winter and cooler in summer; the blocks become stronger with age and exposure, while other materials deteriorate; they are especially valuable for cellar walls and foundations; they are frost-proof and fire-proof, making lower insurance rates; it requires only one-third the time to lay concrete blocks that is required to lay the same area in brick; the hollow wall is always dry; concrete blocks have greater strength in proportion to the material used than could be obtained in solid form; most elaborate designs can be molded for exterior and interior decoration.

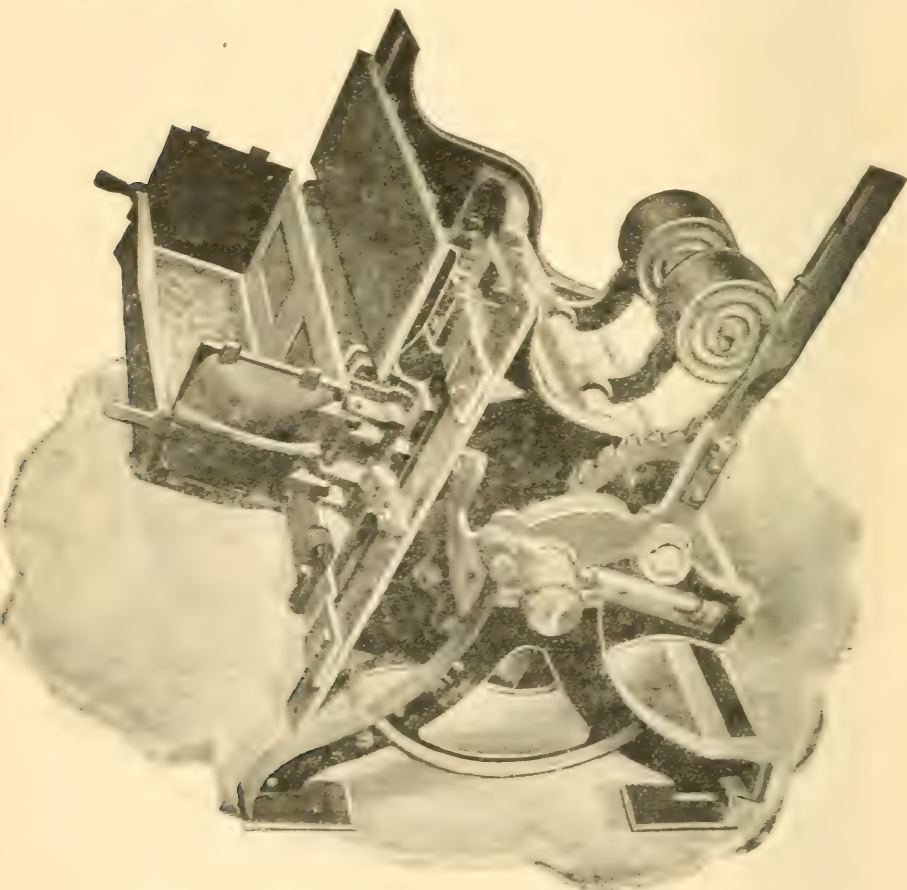


FIG. 52.—Winget Concrete Building Block Machine.

The objections which have been urged against hollow concrete blocks for buildings have naturally been numerous, as new material is apt to be looked upon with suspicion. Faulty work

in their construction has often given good grounds for objection and in some places the faults are better known than the advantages.

One objection often urged is the lack of contrast in the blocks, showing the same tool marks at the same place in every block, giving the building an artificial appearance. One machine with a single mold would give such a result, but the block machine companies make a great variety of molds and a number of these are included with the machine outfit; other forms can be purchased at a low price, so that the maker of concrete blocks can readily furnish a variety of blocks, some of which are illustrated in figure 53. The critical person, looking at a concrete block house is apt to think of it as artificial and so interprets the appearance in accord with his thought. On the other hand,

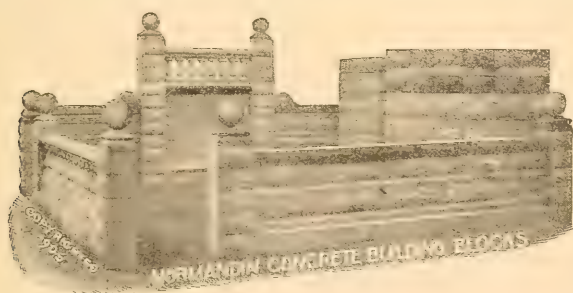


Fig. 53.—Normandin Concrete Building Blocks.

many stone buildings have similar outlines in the blocks of stone, giving the monotonous similarity, which is overlooked as one thinks of the natural stone. In some instances the objection to the artificial appearance of concrete block houses, looking as though they were stamped out of metal, is well founded, but variety could have been given if the maker of the blocks had cared to do so. In many cases the artificial appearance is apt to be only in the prejudiced mind of the observer. Plates XXXIX and XL illustrate types of concrete block construction.

Another objection, about which there is much difference of opinion is one that applies as much or more to stone and brick houses, is the dampness of the inner walls. Examples are cited where the plaster put directly on the concrete block walls becomes

damp. Other cases are given where, in damp locations, such plaster shows no trace of dampness.

The reasons for dampness of walls of concrete block construction are given by E. W. Lazell as,¹

1. Concrete, whether rich in cement or compressed by hydraulic power, will absorb more or less water.

2. The hollow space not being continuous does not prove a barrier to the penetration of moisture as it will travel through the solid portions of the block.

3. Air in the hollow space is not dry air but on the contrary becomes damp in a short time.

4. If moisture is attracted to the hollow space by the process of capillarity then damp air is the result.

Mr. Lazell recommends water-proofing the blocks and suggests the application of paraffine dissolved in some substance so that it could be applied with a brush.

W. H. Finley suggests using asphalt cut with naphtha as a paint over the foundation walls and the surface near the ground. A number of chemical preparations are also sold for this purpose, but their use is not general. Many experienced workers claim that strips nailed to blocks set in the joints of the blocks and then lathed and plastered will avoid any trouble of dampness, while others hold that it is perfectly safe to plaster directly on the blocks if the blocks are correctly made.

In a number of localities the blocks in buildings have cracked and the construction is looked upon as lacking in strength. When many of these cases are investigated, faulty methods of manufacture are found to explain the cause of the cracking. Often the sand, cement and water are so poorly mixed that dry masses are included in the block. The proper curing of the blocks is sometimes neglected. Those workmen who have had no experience in working with cement and concrete see little use in the extra work required to properly cure the blocks. When the blocks are removed from the machine on pallettes they will in a few hours begin to show dry patches on the surface and should then be sprinkled with water. This operation should be repeated every few hours until the blocks can be removed and piled with supports between them to insure drying on all sides. They should be sprinkled with water two or three

1. Cement Age, Vol. I., No. 9, p. 393.

times a day for five to seven days. This method of curing gives opportunity for thorough crystallization of the block, and if followed, and the materials were of good quality and thoroughly mixed, the trouble of cracked and broken blocks will disappear.

The strength of properly made concrete blocks is shown by various tests. At the Watertown Arsenal of the United States Army one-half block of $124\frac{1}{2}$ square inches sectional area showed a compression strength of 504,000 pounds or 4,050 pounds to the square inch, the block was made of a mixture of one part cement to four of sand and tested six months after manufacture.

Two other half blocks one year old and made of one part cement, three parts sand and five parts broken stone showed a strength of 3,040 and 3,084 pounds to the square inch. Such authoritative tests show that concrete hollow blocks can be made of greater strength than would be required in any ordinary building.

Another objection to the appearance of some cement hollow block buildings is the formation of a white discoloration over the surface. This white wash, or efflorescence as it is sometimes called, may be caused by free lime in the cement, and is often a result of improper curing of the blocks. In some cases it is due to an alkali in the water used in mixing the cement. Again, it may be a fault of the cement mortar used in laying the blocks. The use of pure water and proper curing may overcome the trouble in the above cases. Various methods are given for removing the stain. Some advocate making the face of the block of fine sand and larger amount of cement, giving a compact surface, which prevents the stain from coming out of the block. A wash of dilute sulphuric or hydrochloric acid and water has been used to scrub the stain from the blocks, but the removal of the trouble is apt to be only temporary. Various chemical combinations are recommended and some patent preparations are on sale for this purpose. The real solution of this trouble is one of the unsolved problems, but more care used in manufacture of the blocks will go far toward the removal of white wash, which, when present, is a serious detriment to the appearance of hollow cement block buildings.

Concrete building blocks are made of a mixture of cement and sand, gravel or crushed stone in proportions from 1 to 3, to 1 to 7. One barrel of Portland cement will make,¹

11 blocks 32x10x9.....	at 1 to 3 mixture
14 blocks 32x10x9.....	at 1 to 4 mixture
16 blocks 32x10x9.....	at 1 to 5 mixture
20 blocks 32x10x9.....	at 1 to 6 mixture

One hollow block 32x10x9 equals about 42 ordinary size brick. A comparison given for one locality will indicate the comparative cost of the cement blocks and brick.²

200 blocks 32x10x9 equal approximately 8000 brick.	
200 blocks cost to manufacture.....	\$36.00
200 blocks cost to lay in wall.....	14.00
	\$50.00
8000 brick at \$6.00 cost.....	\$48.00
8000 brick at \$5.00 cost to lay.....	40.00
	\$88.00

Eight thousand pressed brick laid in the wall would cost \$240. While these prices are local and for a given time only, they show an economy of first cost for hollow cement block.

With reference to the cost of manufacture,¹ one machine and five common laborers can make 140 to 200 full size blocks a day. One barrel of cement and four barrels of sand will make 14 full size blocks (10 inches thick). In one yard of sand there are about 8 barrels. For a 1 to 4 mixture 140 blocks would require 10 barrels of cement and 40 barrels of sand, which would make the cost of 140 blocks,

10 barrels cement at \$1.50.....	\$15.00
5 yards sand at \$1.00.....	5.00
5 laborers at \$1.50.....	7.50
	\$27.50

or one block would cost less than 20 cents. This is equivalent to 42 brick and would be reasonable at 50 cents. Twenty-four blocks are equivalent to 1000 brick (2x4x8), so would cost \$4.80, or at 50 cents would be equivalent to \$12.00 a 1000 for brick. A

1. Normandin Machine Catalogue, Jackson, Mich.

2. Rock Products, Vol. III., No. 8, p. 34 B.

1. Palmer Machine Catalogue, Washington, D. C.

mason will lay 150 to 200 blocks a day, equivalent to 6300 brick. Contracts have been let at 5 cents each for laying the blocks.

As to architectural effects these blocks can be made in a great variety of sizes and shapes, simply by changing the mold plates in the machine. One company lists 30 of these mold



Fig. 54.—Residence Constructed of Normandin Concrete Blocks.

plates and new designs are continually being made. The cement blocks make a fire-proof wall and the small amount of damage done to these houses in large fires has been noted in a number of localities.

REINFORCED CONCRETE.

In the construction of bridges, tall chimneys, large buildings, etc., the concrete is strengthened by metal reinforcement, and is then called reinforced concrete, armored concrete, or steel concrete.

Experiments show that the tensile strength of concrete is low, but the compression strength is high. The tensile strength of steel is high and the adhesion strength of concrete and steel is over 700 pounds to the square inch, so that the two substances taken together make a very strong building material.

The real inventor of this combination was a French engineer, Monier,¹ who tested its use in 1866. Later Hennebique, through his engineering company and methods of construction, established the industry. The method of reinforcing concrete consists of placing expanded metal wire, or rods laid in the concrete. In beams, the rods are placed in the lower part of the concrete body with ends near the beam end extending upward. Additional rods may run obliquely or vertically from the upper to the lower portions of the beam. Some engineers claim that the adhesion between concrete and the steel rods is greater when corrugated, twisted or deformed bars are used and the patents are usually held on the form of steel bar used.

Reinforced Concrete Girders.

The greater strength of the steel concrete permits the use of very long girders, longer than those made of steel alone, and they carry a less amount of dead weight in the girder. The girders are practically fire proof and can be placed in position rapidly. The steel imbedded in the concrete is found on removal after many years to be free of rust.

Tests made on steel concrete beams show great strength, greater than that of steel alone. In the new Lyric theater at Cleveland, Ohio,² is a span of 57 feet, over which the girder was calculated to carry a distributed load of 65,000 pounds. It was tested by hanging a load of 88,000 pounds from the center, equivalent to a distributed load of 176,000 pounds, and the greatest deflection was 9-16 of an inch, and the permanent deflection was less than 1-8 inch. The reinforcement placed in the lower part of this girder consisted of eight 1-2 inch steel rods.

A concrete beam 102 feet long and less than 2 feet thick forms a part of the support for the roof of a new ware house at Los Angeles, Cal. It is reinforced by six iron bars running

1. Concrete, Vol. I., No. 1, p. 8.

2. Concrete, Vol. I., No. 1, p. 9.



Plate XLIV.—Weight Test on a Section of Reinforced Concrete Sewer Pipe.

through the entire length, and under the test the settling of the beam was less than 0.68 of an inch.¹

Reinforced Concrete Buildings.

In the construction of modern fire-proof buildings it has been estimated that the use of steel concrete, in addition to its advantages of fire-proof character, rapidity of construction, etc., represents a saving of nearly 25 per cent. in actual cost.

The construction of these large buildings of concrete has now passed beyond the experimental stage and has become the common method in many of the cities of this country. These buildings require a large quantity of cement and have greatly increased the demand.

One of the largest reinforced concrete factories in this country has recently been completed at Beverly, Mass., the plant of the United Shoe Machinery Co., consisting of ten large buildings with a floor space of ten acres.² The two main buildings are 522 feet long, 62 feet wide, and 58 feet high. There are two concrete girders in the roof of the power house, 50 and 40 feet in length. There is also a concrete chimney 140 feet high with an inside diameter of six feet. In the construction of these buildings, 63,000 barrels of American Portland cement were used, and the total cost of the buildings was \$3,000,000.

One of the first large reinforced concrete buildings was the Ingalls building in Cincinnati, covering an area 100 by 50 feet, with a height of 210 feet. It contains sixteen stories, with basement and sub-basement. The first three stories are faced with marble, and the others with glazed brick and terra cotta trimmings.

The Pugh power building in Cincinnati is 68 feet wide, 335 feet long, and ten stories high.³ The floors are arranged for a load of 230 pounds per square foot and the whole structure is made of reinforced concrete. The area of the building is 22,000 square feet and the reinforcement consists of round, medium sized steel rods. The concrete was mixed in the proportion of one part of cement to two parts sand and four parts

1. The Cement Age, Vol. I., No. 12, p. 566.

2. Concrete, Vol. IV., No. 1, p. 7.

3. The Cement Age, Vol. I., No. 12, p. 519.

crushed stone. About 8,000 cubic yards of concrete were used and 800 tons of steel. The cost of the building was \$225,000. The walls, stairways, ventilator shafts, partitions, and floors are all of concrete.

Concrete Roofs and Floors.—The roof of the Chittenden Power Company power house at North Rutland, Vermont,¹ is made of concrete slabs which are $9\frac{1}{2} \times 4 \times 3\frac{1}{2}$ inches. On the bottom was placed a layer of neat cement, $\frac{1}{2}$ inch thick, upon which is a sheet of expanded metal. Concrete composed of one part cement, two parts sand and three parts crushed stone was tamped in and the upper surface roughly troweled. The slabs are fastened to the roof by one-half inch steel rods, the joints pointed with neat cement and the roof then water proofed.

Concrete floors are used for fire-proof construction (plate XLI). Twenty patented systems are approved by the city of New York.² The DeMann floor block consists of I beams, reinforced by webs and flanges. The Visinti system consists of concrete girders in which a steel framework is imbedded. Other systems have iron rods imbedded in the lower part of the mass and are supported on the steel concrete beams of the building. Some of these floor blocks span an interval 18 feet square and are only 4 to 5 inches thick. Stairways, columns, balustrades, elevator shafts, are now made of steel concrete to give complete fire-proof construction.

Cement Roofing Tile.

Roofing tile of the Christensen patent³ is made of cement in one foot squares. It has raised ridges on two edges on the under side and corresponding indentations on two edges on the upper side so that the tiles fit together closely and are water proof. The weight of the tile is claimed to be one-half that of the best roofing slate. The machine for their manufacture enables one man to mix and make 150 to 175 tiles a day. The tiles have withstood severe freezing and high temperature tests.

The first use of cement in a crude form as roofing material, according to H. J. Fuhrman,⁴ was in Bavaria in 1840, and after

1. The Cement Age, Vol. II., No. 1, p. 30.

2. The Cement Age, Vol. I., No. 6, p. 174.

3. Concrete, Vol. II., No. 1, p. 23.

4. Rock Products, Vol. III., No. 2, p. 48.

39 years the tile were exhibited at the Exposition at Arnheim, Germany, and were in good condition, with no sign of wear. Since 1878 cement roofing has been used successfully in Germany, France, and Belgium. In Germany there are 267 cement roofing tile plants.

A number of plants have been started in this country in the last two years. The Detroit Cement Tile Co. started in 1904 and has covered over 80 roofs in that city. With the Furman New Era tile machine one man can make 250 to 275 tile a day, which are dried 24 to 48 hours, then piled away and watered three times a day for four days, then left to season for 30 days, when they are ready for the roof.

In the year 1904 the McKeesport (Pa.) Cement Tile Roofing Co. began operations and in 1905 enlarged their plant. Factories were established in 1904 at Saginaw, Michigan, and Roswell, New Mexico.

Cement floor tiles are also made in any desired color and shape. They are made under high pressure up to 40,000 pounds per square inch. Three men can make 1000 to 2500 tiles a day on hand or power presses.

Fire-Proof Character of Concrete Buildings.

The Ransome Concrete Company, of New York, erected in 1900 a small concrete building to be tested by fire and water.¹ It was 10½ feet wide, 14 feet long, with a clear height of 10 feet above the grate bars which formed the floor. Three of the walls were of concrete and the fourth of brick. The building stood one year, then fires were started on the grates and kept replenished with old lumber. In ten minutes the temperature by a standard pyrometer was 842 degrees Fahrenheit and later reached 1967 degrees. An average temperature of 1700 degrees was maintained for four hours, then a large door was opened and a heavy stream of water directed against the concrete walls and ceiling for five minutes. The concrete walls remained true to line and at no time were so warm that the hand could not rest comfortably against them. The brick wall was badly cracked, while the strength of the concrete walls was not seriously

1. Concrete, Vol. III., No. 5, p. 14.

injured. The permanent deflection of the roof, which had been loaded to 158 pounds per square foot, was only $\frac{1}{4}$ inch.

In actual fires, some of the most noted examples of the fire-proof qualities of concrete were in the great Baltimore fire of February, 1904. The United States Fidelity and Guarantee Company building, made of concrete, was in good condition after the fire, although it was the only one left in the block. The temperature to which this structure was exposed has been estimated at 3,000 degrees. The concrete was calcined to the depth of a small fraction of an inch and, according to the report of Capt. Sewell, could be repaired at about 20 to 25 per cent. of the original cost. After the fire one of the floors was tested by a load of 225 pounds to the square foot and the deflection was only 1-16 of an inch.

In the fire at the works of the Pacific Borax Company, at Bayonne, N. J., in April, 1902, the main building of steel concrete was but little injured, while a wing of unprotected steel construction was twisted out of shape. In rebuilding, the company has used steel concrete throughout.

Many other similar examples might be cited, but these few will show the value of reinforced concrete for fire-proof structures. These actual experiments in large fires with the successful outcome with steel concrete construction have given a great impetus to the industry.

Concrete Chimneys and Stand Pipes.

Reinforced concrete is now used in building high stacks, stand pipes, and lighthouses. It is adapted to these uses on account of the small amount of weight in proportion to the required strength, its durability, and its resistance to injury in the presence of high winds or waves. The small thickness of the walls in these structures is remarkable when considered in connection with their height.

A stand pipe was erected at Milford, Ohio, 84 feet high and 14 feet in diameter. The wall for the first 30 feet is only 9 inches thick, the next 25 feet the thickness is 7 inches, and the upper portion 5 inches. The concrete was made of one part Portland cement to three parts aggregate, and reinforced with T shaped bars.

A concrete lighthouse¹ was built in Russia at the entrance of the canal connecting Ft. Nikolaev with the Black Sea. It is $132\frac{1}{2}$ feet high, resting on a concrete foundation nearly 20 feet in diameter and 8 feet deep. The tower is $20\frac{1}{2}$ feet in diameter at the base and $6\frac{1}{2}$ feet at the top. The walls at the bottom are 7 2-3 inches thick and a little less than 4 inches at the top. The reinforcement consists of longitudinal and transverse rods. The structure was built in two months at a cost of \$6,000,000 and contains 507 tons of concrete.

The chimney at the new Seelbach hotel, Louisville, Ky., was built by the Weber Steel Concrete Co., of Chicago.² It is $176\frac{1}{2}$ feet high with an inside diameter of $4\frac{1}{2}$ feet. The lower 78 feet has an outer shell six inches thick and an inner shell of four inches, separated by a four inch air space. The remaining portion is a single shell five inches thick. The reinforcement consists of T iron according to the Weber system. The total weight of chimney and foundation is about 266 tons. A view of this chimney is shown in plate XLII.

The same company erected for the Burt Portland Cement Company, at Bellevue, Michigan, a chimney 182 feet in height, consisting of two shells to a height of 60 feet, and from this point a single shell, tapering from eight inches to five at the top. This chimney was built at a rate of about six feet a day.

The tallest concrete chimney in the world, at the present time, is one built for the Tacoma Smelting Co., in Washington State.³ The chimney is $307\frac{1}{2}$ feet high, the first 90 feet consisting of two shells, the outer nine inches and the inner four, separated by an air space of five inches. The rest of the chimney is a single shell seven inches thick. It was completed in 50 working days and the cost was \$28,000.

Reinforced Concrete Arches and Bridges.

On account of the strength of reinforced concrete, its protection of the inclosed metal, and the low cost of repairs, and the freedom from vibration, concrete bridges have become more and more popular.

1. Concrete, Vol. II., No. 6, p. 14.

2. Concrete, Vol. III., No. 3, p. 23.

3. The Cement Age, Vol. II., No. 3, p. 191.

One of the first types of concrete bridge construction in this country was the Melan arch introduced especially by the work of Edwin Thacher. Wooden forms gave the shape of the arch and over these were bent the iron reinforcing rods, and the concrete was poured over and around these. The bridges became quite popular in short spans in parks and on driveways, but later were used in large bridges over the Kansas river at Topeka, the Y bridge over the Muskingum and Licking rivers at Zanesville, Ohio, and others.

A number of railroads are now using steel concrete for small and large bridges. The Lake Shore and Michigan Southern bridge at Ashtabula contains 17,000 cubic yards of concrete.¹ The bridge of the same company at Willoughby is one of the largest concrete spans yet built, being 153 feet and containing 10,000 cubic yards of concrete.¹ The Big Four railroad bridge near Guilford, Indiana, is 320 feet long and contains nearly 6,000 cubic yards of concrete.

Over the Yellowstone river in the park is a wagon bridge² with 160 foot span and a width of 18½ feet. The bridge floor is 43 feet above the water and the structure was built in 75 hours with a force of 150 men. The total volume of concrete used was a little less than 900 cubic yards, made in proportion of one part cement to two parts sand and four parts broken rock.

At Topeka a Melan arch bridge was built across the Kansas river in 1898. The total length of the bridge spans is 540 feet, or, including the piers, 625 feet, and with the approaches is 900 feet in length with a width of 40 feet. Eight thousand barrels of cement, 8,278 cubic yards of broken stone, 5,000 cubic yards of sand, and 140 tons of steel were used in its construction. The total weight is 17,600 tons and the cost was \$150,000. This bridge passed through the disastrous flood of 1903 with no damage to the bridge proper, though the approaches were badly damaged and one washed out. It was the only bridge on the river not damaged at this time. Plate XLIII gives a view of the longest concrete bridge in the world, completed in 1905.

1. Concrete, Vol. II., No. 6, p. 13.

2. Eng. News, Vol. 51, p. 26.

Concrete Piles.

Concrete has been used in place of wood piles for supporting structures over ground which is not firm enough for safe foundation work. This use has not become as common as the use of concrete in buildings, but is growing in favor on account of the economy and durability of concrete piles.

The Simplex concrete piles have been used for the foundations of the new buildings at the Washington (D. C.) barracks and many large structures. The Simplex pile consists of a metal pipe with a detachable point of concrete or cast iron which is driven into the ground to the required depth. The pipe is slowly withdrawn as the concrete is forced in.

In a number of Chicago buildings, Marshall Field store, First National Bank building, Railway Exchange building, the supports for the foundations were made by sinking shafts 85 feet in depth to the solid rock and filling these with concrete. In the Raymond pile, a steel shell with a collapsable core is driven, and when in place the core is withdrawn and the shell filled with concrete.

The Hennebique reinforced concrete pile has iron rods around which the concrete is poured, forming a nearly square pile with any required length, with a steel cone or shoe fastened to the bottom. They have been extensively used in England and Europe, especially for wharves, as they are not injured by boring shells which soon destroy wood supports.

Railroad Ties.

It has been estimated that over 100,000,000 ties are used on the railroads of this country. The cost of wood ties has increased from year to year, and the problem of future supply is a serious one through the growing scarcity of timber for this purpose. Experiments have been carried on in this country and abroad on cement ties to replace wood. Up to the present time the value of cement ties, under present methods of construction, has not been wholly proved, but it appears very probable that a satisfactory cement tie will be made and add a new demand for cement. One form of cement ties is shown in plate XXXIX.

The Buhrer cement tie¹ is made of concrete, reinforced by discarded steel rails inverted so that the flat base of the rail formed the top face of the tie. These ties weigh 400 pounds each, are 8 feet long, 6½ inches deep and 9 inches wide at the base. In 1903 a roadbed for a distance of 1200 feet was laid with these ties near Danbury, Illinois, by the Lakeside and Marblehead railroad. The ties were placed 21 inches apart and the track ballasted with limestone screenings. They were placed on a curve and subjected to heavy traffic which has been successfully withstood. The same form of tie has been used experimentally on the Wabash and Pennsylvania lines.

The Kimball tie¹ used on a trial section of the Pere Marquette road consists of two blocks of concrete, one under each rail, the blocks measuring three feet long by nine inches wide and seven inches deep. Two three-inch channel beams the length of the tie are molded into the blocks connecting them. A bearing surface for the rail consists of an oak block molded in the tie and secured by bolts to the channel beams. The ties weigh 436 pounds and cost \$1.30.

In Europe the cement ties are reinforced by small rods. On the Adriatic railroad trial ties were laid in 1900, consisting of concrete reinforced by small steel rods. The length of the ties is 8½ feet, the weight 287 pounds, the section at center 31 square inches, and the section of the steel rods three square inches. The cost was \$2.20 each, while wood ties cost \$1.00, but the cement tie was estimated to last 30 or 40 years, while timber ties last but 5 or 6 years.¹

Concrete Fence Posts.

Fence posts² are now being made of reinforced concrete at a number of localities and appear to give satisfaction. In one system they are made of one part cement to four to seven parts sand, reinforced by wood, gas pipe, or wire. The objections urged against their use have been the weight, poor arrangements for fastening wire or, more especially, boards to them. They have also been regarded as brittle and sensitive to any

1. Concrete, Vol. II., No. 4, p. 16.

2. Concrete, Vol. III., No. 3, p. 21; No. 6, p. 10; Vol. IV., No. 3, p. 11.

sudden jar. The experiments made at Iowa State College gave a breaking load of 292 pounds for cement posts, while white ash posts stood 2230 pounds, and white pine 1540 pounds. The sudden jar of a weight of 80 pounds falling two feet broke the post. The conclusions reached from these tests were that such posts should be placed close together and that they would be profitable only where wood was scarce and farmers could make their own posts on the ground.

According to the conclusions of C. L. Catherman,¹ five sets of cedar posts to last 40 years would cost set in the ground about \$1.00, while cement posts would cost less than 20 cents and last 40 years or more. He estimates the cost of a seven-line post as follows:

12 to 16 pounds of cement (at \$1.50).....	5 to 6 cents
2 pounds of metal.....	5½ "
½ cubic foot of sand or gravel.....	1 "
Labor 2 men (making 100 posts a day).....	3 to 4 "

Total cost of one post.....15 to 17 cents

The posts selling at 50 cents would be regarded as low in price.

H. A. Low¹ claims the best reinforcement would be steel wire cabled tightly in the corners of the post about one-half inch from the edges. He recommends the wet process of mixing the concrete as giving a denser body with a glazed surface impervious to moisture and also preventing displacement of the wires by tamping. The posts should be set aside to cure and should be well sprinkled with water for 20 to 60 days, the longer time being better. He estimates that over three billion wood fence posts are now in use in this country. Actual experiments show that concrete fence posts in use for 12 years are still good and it is claimed that cement posts are seldom if ever broken in use.

Concrete Dams.

Modern large dams are now constructed of cement, usually reinforced. The Upper Otay dam, in Southern California, completed in 1900, is an arched steel concrete structure, 350 feet long and 84 feet high, reinforced by steel plates and cables. The thickness at the bottom is 14 feet, decreasing to 4 feet at the

1. Concrete loc. cit.

top. A view of the Wilton, New Hampshire, dam is shown in plate XLI.

Concrete, usually without reinforcement, is extensively used for piers, abutments, reservoirs, and with reinforcement for filtration plants and aqueducts. The Mexican Government is constructing a nine million dollar aqueduct between Xochimilco and the City of Mexico. This structure will be 15 miles long, five feet high and six feet wide, requiring 200,000 square metres of expanded metal.

The Galveston sea wall has been constructed to prevent the danger of future inundations of that city. It was begun in October, 1902, and completed in July, 1904. The wall is $3\frac{1}{2}$ miles long, 16 feet wide at the base and 5 feet at the top, which is 17 feet above low tide. The base is protected by granite blocks, extending out 27 feet into the Gulf. The concrete wall is reinforced by steel rods 9 feet long, set obliquely. In the construction of this sea wall, 150,000 tons of concrete, containing over 140,000 barrels of cement, were used with ten car loads of metal. The cost was nearly two million dollars.

The concrete sea wall at Scarborough, England,¹ is 4200 feet long, 40 feet high, 30 feet wide at the bottom and 10 feet at the top. It is built of concrete blocks, each weighing from two to nine tons, and over 1500 were used.

Concrete was used for the Port Colborne, Ontario, break-water, 2400 feet long. The crib-work of the wharf at Depot Harbor, Ontario, 400 feet long and 150 feet wide, is constructed of concrete.

Concrete Sewers.

Concrete sewers have been built in New Orleans, Cleveland, Columbus, Boston, Wilmington and other large cities.

The Cleveland main intercepting sewer² is $13\frac{1}{2}$ feet in interior diameter and $3\frac{1}{2}$ miles long. The reinforcement consists of $2\times\frac{1}{2}$ inch steel anchor bars, with transverse tension bars above bolted to them. The steel was placed over the wood forms and three inches of cement mortar laid upon the forms enclosing the bars; then the concrete was rammed upon this mortar

According to W. C. Parmley,³ sewers can be built of con-

1. Eng. Record, Vol. 50, No. 20, p. 570.

2. Ohio Geol. Survey, Bull. No. 2, p. 169.

3. The Cement Age, Vol. I., No. 12, p. 527.

crete equal to or greater in permanency than one formed of brick, and the outside finished with one inch of cement mortar. The average cost of the sewer was \$62.00 per lineal foot, as compared with \$75.00 for brick construction.

It makes a smoother interior wall, thus giving an unobstructed flow to the water. It is more water tight, it is less liable to damage and collapse through excessive loads that may be brought upon it, and is cheaper in cost of construction. The strength of concrete sewer pipe is illustrated in plate XLIV.

Concrete Bins.

The Canadian Pacific railroad grain elevator at Port Arthur, Ontario, has nine steel concrete bins, 30 feet in diameter, 90 feet high, with walls 9 inches thick. They are reinforced laterally and vertically. The total capacity of the elevator is 440,000 bushels.

The Illinois Steel Company, at South Chicago, has four steel concrete bins, 25 feet in diameter and 53 feet high, with walls 5 to 7 inches thick, used for the storage of cement, giving a capacity of 25,000 barrels. The reinforcement consists of wire mesh supported by circular rods.

Miscellaneous Uses.

Concrete has been used for fire-proof bank vaults by the First National Bank of Norwood, Ohio, and the walls of the vault were made six inches thick.

The grand stand of the athletic field of Washington University, at St. Louis, is made of concrete. It is nearly 800 feet long and will seat 9,000 people. At Harvard a concrete grand stand of U shape is 573 feet long, 420 feet wide, and will seat 20,000.

Silos, water troughs, tanks, burial vaults, water pipe, electric conduits and many other structures have been made from concrete. On the C., B. & Q. Railroad the signal posts have been made of concrete. The Chicago & Eastern Illinois Railroad is using a concrete mile post, 8 inches square and 5 feet high above the ground, with a weight of 500 pounds. Concrete bases are made for telegraph poles, and after three years' use are pronounced satisfactory. They represent a saving in the life of the post, as the portion of the wood pole in the ground rots away in a few years.

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